Making Sense of the Salmon Aquaculture Debate

Analysis of issues related to netcage salmon farming and wild salmon in British Columbia

Prepared for the
Pacific Fisheries Resource Conservation Council

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1 THE SALMON AQUACULTURE DEBATE: HOW DID WE GET HERE AND HOW CAN WE MOVE FORWARD?

Salmon aquaculture is a subject that contains multiple scientific and policy issues. Those who favour expansion maintain that many of these scientific issues were conclusively dealt with during the Salmon Aquaculture Review of 1997. Their opponents argue that those research findings were incomplete, not sufficiently impartial, or have been superseded by more recent, differing findings. As interested citizens observe the debate and strive for informed opinions, a continuing refrain is that "we don't know whom to believe."

Although current articles, position papers and radio and TV interviews present some of the pertinent scientific information, they often do so in a headline, sound-bite, summary fashion. There is a need for more thorough, rigorous review of research and analysis on many aspects of salmon farming. This report, commissioned by the Pacific Fisheries Resource Conservation Council (PFRCC), aims to help fill that gap.

The PFRCC was established in 1998. Its role is to provide independent, strategic advice and relevant information to the federal and B.C. provincial fisheries ministers and the Canadian public on the status and long-term sustainable use of wild salmon stocks and their freshwater and ocean habitats. *This report supports the PFRCC in this role by illuminating issues related to the interaction of salmon farming with wild salmon.*

1.1 Goal, scope and contents

As government agencies, First Nations, industry representatives and environmentalists advance their positions on salmon aquaculture, it becomes difficult for the public to distinguish rhetoric from reality. The Hon. John A. Fraser, the Chair of the PFRCC, stated at an international conference in 1998, regarding the state of fish stocks and habitat, "here on this coast, we have listened to so much self-serving rhetoric from different groups that it has been extremely difficult for the public to know what is the truth. The 'disconnect' is really quite extraordinary." (Fraser 1998, p.25) The same may be said of the highly charged debate about the impacts of salmon farming on wild salmon.

More needs to be done to independently evaluate arguments and determine their validity. This report aims to fill this need by looking behind the debate to examine the information and assumptions supporting the arguments of opposing interests. Thus, the goal of this report is:

> ***To expand and deepen the current public understanding about the potential impacts of salmon aquaculture on wild salmon by examining, evaluating and assessing the information and assumptions supporting the arguments of opposing interests.***

This focus on the interplay of salmon farming and wild salmon means that the analysis does not cover all aspects of the potential impacts of salmon farming. Nor does it explore all of the pressures on wild salmon. Instead, the report concentrates on the most pressing issues pertaining to farmed salmon-wild salmon interactions.

The three main areas of investigation are:

- **Disease and Fish Health** – Is there evidence that diseases are transferred between salmon farms and wild stocks? Have salmon farms introduced new diseases to B.C.? Do salmon farms increase the presence of sea lice in surrounding waters?
- **Escapes** – What is the magnitude of salmon escaping from B.C. salmon farms? Are escapees, particularly Atlantic salmon, spawning successfully in B.C.?
- **Habitat Impact** – What is the impact of salmon farms on water quality and adjacent seabeds? Do chemicals used on the farms affect wild salmon?

Issues that fall outside of the scope of this report include:

- other forms of aquaculture such as non-salmon fin fish or shellfish farming;
- impacts of other threats to wild salmon: climate change, hatcheries, habitat loss, commercial and sport fishing, pollution, exotic diseases imported by mechanisms other than salmon farming;
- other potential impacts of salmon farming: the "ecological footprint" of salmon farming related to the production of feed for aquaculture, potential impacts on human health, ecosystem-level impacts, potential impacts on other species such as groundfish and bivalves;
- the benefits of salmon farming: economic, employment and community stability, food source;
- values of wild salmon: cultural, spiritual, food, economic, ecosystem, biodiversity;
- legal implications of impacts on wild salmon with respect to the fulfillment of government mandates, particularly the federal government's fiduciary responsibility to First Nations;
- the level of adoption and the effectiveness of mitigative measures;
- the appropriateness and effectiveness/compliance rate of guidelines, protocols, policies and regulations;
- the appropriateness and effectiveness of monitoring and enforcement;
- economic factors including costs and benefits of environmentally protective measures in salmon farms, government economic incentives, market forces, and the economic interactions of aquaculture and the wild salmon industry; and
- technologies of salmon farming in other than net pens in the ocean (e.g., closed containment on land or in the water) and their relative potential impact.

Following this introduction, which explains the approach and offers more context for the issues at hand, some ideas about science and risk are presented as a foundation for the analysis. Next, the three main chapters of the report examine the issues of disease, escapes and habitat.

Within each of the chapters on disease, escapes and habitat, the discussion generally follows in five main sections:

- The issue is explained in terms of the biology and/or technology and ecological processes involved.
- The key issues of debate are analyzed in terms of two general points of view on each issue. One point of view represents arguments supporting lower risk estimates in relation to the issue; the other point of view represents arguments supporting higher risk estimates in relation to the issue.

- Ways of mitigating the associated problems are reviewed.
- Gaps in the relevant knowledge base are summarized.
- An assessment of the risks posed to wild salmon is provided.

The chapter on disease is more extensive than the other two main chapters because the literature on escapes and habitat issues is more limited than the literature on disease. Scientific research on escapes and habitat impacts in other areas is not generally applicable to British Columbia, while studies of disease in other jurisdictions are pertinent.

In Section 6 of the report, conclusions draw together the risk assessments from the three main chapters.

Appendix 1 provides detail on the precautionary principle, in connection with Section 2.2 of the report. Appendix 2 reviews existing regulations and monitoring requirements. Note that these appendices have their own lists of references, distinct from the references for the report listed in Section 7. There is a list of abbreviations at the end of the report, after the appendices. Just prior to this list is a glossary of technical terms.

1.2 Background to the current debate: decades of controversy

The salmon aquaculture debate has been a feature of British Columbia life since the mid-1980s. There have been multiple inquiries, reports, reviews, studies, conferences and campaigns – at least from the time of the Gillespie Inquiry of 1986. Some of the more recent milestone events have been the Salmon Aquaculture Review of 1997, the Leggatt Inquiry of 2001, Senate and House of Commons Fisheries Committee hearings, and the B.C. Aboriginal Fisheries Commission's (BCAFC) Fish Farm and Environment Summit of September 2002. Through this time the science has evolved, but it remains uncertain on most issues. And there has been continuing pressure – from one side, to limit expansion or even reduce the industry until more is known about its risks, costs and impacts; from the other, to expand while balancing risks and economic rewards.

At the start of this research project in the summer of 2002, with the anticipated lifting of the salmon aquaculture moratorium and with farmed salmon already ranked as B.C.'s leading agri-export, the stage was set for potentially rapid expansion of the industry. Throughout 2002, salmon aquaculture in British Columbia has continued to be a controversial, high profile subject. The provincial government announced at the end of January that it intended to lift the seven-year moratorium on expansion of the industry at the end of April, and that it would issue regulations to govern the expanded industry. The eventual lifting of the moratorium, in September 2002, further fueled interest.

Through the year, the subject of salmon aquaculture has remained a popular and on-going topic of discussion in the B.C. media (newsprint, television and radio – particularly talk radio). The combined effect of publicity surrounding the lifting of the moratorium and media coverage of escapes and diseased fish problems has been to spark heightened public interest in the subject matter. Industry, environmentalists and First Nations have been active in presenting and seeking support for their points of view.

As of the completion of this report, it is not clear whether the pro- and anti-salmon farming interests are closer to or farther from reaching consensus on the issues. On one hand, there seems to be an increased willingness of all sectors to focus their attention on commonly acknowledged problems and issues. A B.C. Aquaculture Research and Development Program has been established (MAFF 2002a), and more meetings and conferences on salmon aquaculture issues are scheduled for the coming year. On the other hand, there are forces that could move the parties farther apart. Anti-salmon farm interests are currently directing their efforts toward international market campaigns to apply pressure for change.

This report aims to help inform the continuing dialogue by summarizing arguments and the information behind them, and providing an analysis of the uncertainties and risks posed by the interaction of salmon farming with wild salmon.

1.3 Approach

This project is not an inquiry or a public consultation, unlike others that have recently addressed salmon farming in the public forum. Rather, it has involved research, interviews, analysis and reporting. The resulting document aims to support a meaningful discussion of the issues surrounding the potential impact on wild salmon of salmon aquaculture by meeting three conditions:

- It objectively examines the scientific basis for the arguments made by industry, government, First Nations and NGOs;
- It presents information clearly and simply to help citizens understand and develop informed opinions; and
- Its findings and conclusions are thoroughly documented.

The research began by identifying key issues related to the interplay of salmon aquaculture and wild salmon. Initial research focused on readily accessible literature from:

- Websites and list-serves;
- libraries (University of British Columbia, PFRCC);
- electronic journals;
- recent media reports;
- government reports;
- policy and regulatory documents;
- workshop and conference reports;
- the publications of stakeholder groups and governments; and
- the results and transcripts of recent inquiries and public consultations (as well as submissions to those processes).

During the initial research, in consultation with members of the PFRCC, selected experts were identified to interview. The purpose of this small set of interviews was to comprehend the source of debates, ensure understanding of current information, and obtain referrals to relevant documents and publications. Interviewees were selected who would have at least some scientific understanding of the issues, and who could help illuminate the range of viewpoints in the debate. Representation of the different stakeholder groups was not the driving factor – the interview process was not intended to be a consultative process or a survey. The emphasis instead was on finding key experts in the scientific fields relevant to the central issues, to complement print resources. The number of interviews is low because the emphasis of the research was on published information and because little new information was coming to light by the end of the interviews. Virtually all of the interviewees contacted were willing to contribute their time to interviews by telephone or face-to-face (one in Ottawa, several in Campbell River, and the remainder in Greater Vancouver). In all, 38 interviews were conducted. Interviewees are listed in sections 7.2 and 7.3 of this report.

An interview template was designed to guide the interview process, but most interviews were unstructured, driven by the particular experience and expertise of the interviewee, and the specific research questions relevant to that expertise.

The researchers also made field trips to the following:

- a research facility – the West Vancouver laboratory of the University of British Columbia's Centre for Aquaculture and the Environment;
- a salmon farming hatchery – Marine Harvest's Big Tree Creek Hatchery;
- a salmon farm raising Atlantic salmon – Heritage Salmon Limited's Venture Point farm;
- a salmon farm raising chinook salmon – Marine Harvest's Young Pass farm;
- a processing plant – the Brown's Bay Packing plant at Brown's Bay, including tour with Ken Pike, Manager.

The interviews helped to identify additional relevant publications and "grey literature" (e.g., conference presentations, reports of meetings and research, and policy documents with limited circulation).

Finally, the researchers attended three public events focused on topics relevant to the research:

- a public presentation by Dr. John Volpe, "Science Friction: the Incredible Story of Atlantic Salmon in B.C.," Vancouver, March 21, 2002;
- a public presentation on the impacts of the salmon farming industry in Chile with Marcel Claude, Founder and Executive Director of the TERRAM Foundation, former Director of the Natural Resource Accounting Department, Chilean Central Bank, North Vancouver, September 23, 2002;
- the Fish Farming and the Environment Summit, a Public Summit on Salmon Farming Hosted by the B.C. Aboriginal Fisheries Commission, Sept. 24-26, 2002, North Vancouver.

Given the intended role of this report as an "honest broker," ways of ensuring impartiality were critical to the research approach. To this end, the researchers adopted the following practices:

- careful consideration of, and reporting on, the relevant scientific information;
- attention to the advice of a range of key scientists from different backgrounds and accurate reporting of what they say;
- open-minded review of all the print information;
- separation of perceptions from strong evidence;

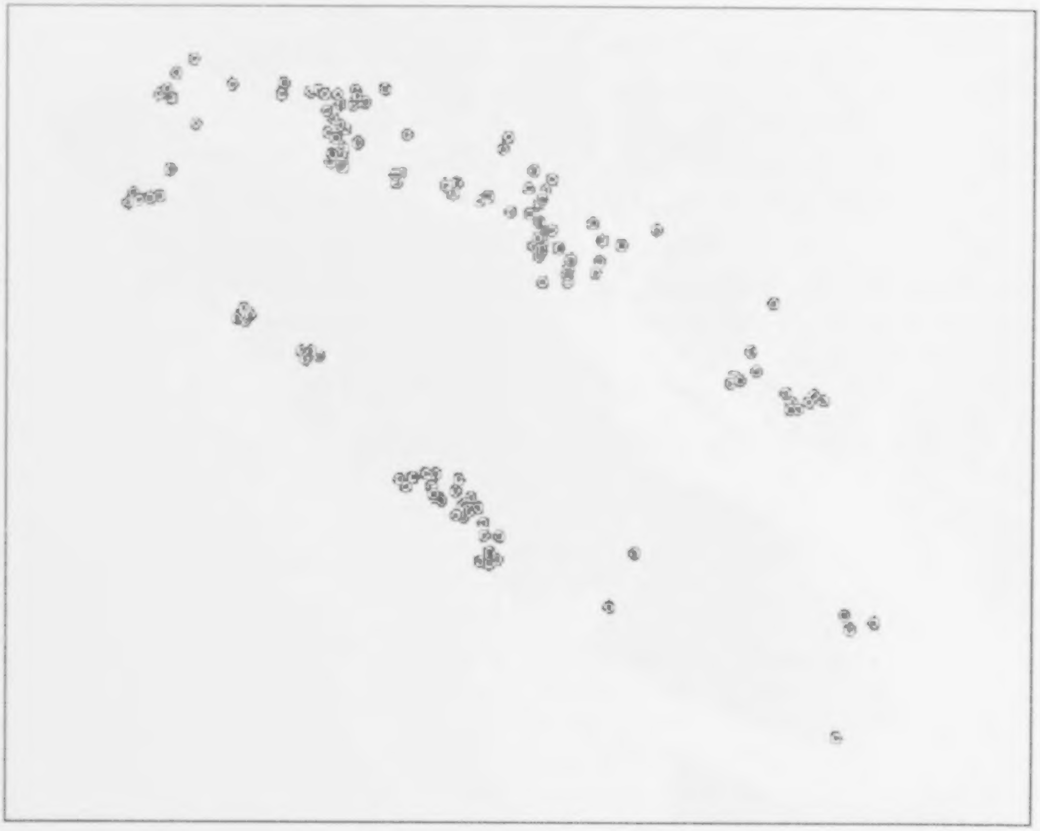
- consideration of the perspectives, and more importantly, the information used by, the range of interests involved;
- full disclosure of our information sources.

As indicated in the preceding historical review, shifting sands of events, publicity, scientific information and public interest in the interplay of salmon farming and environment mean that new practices, new evidence and new issues will continue to arise. The research reported here was completed in November 2002, and therefore represents a snapshot in time of the state of affairs as of that month.

1.4 Salmon farming in British Columbia: a brief introduction

As of October 2002, the B.C. salmon aquaculture industry operated 121 farm sites (tenures) of varying sizes (see Figure 1). The industry was capped at this number of sites in 1995. Eighty-three of the sites are active, with the remainder inactive. Thirty-six are in the process of relocation. Most are located around and inside of Vancouver Island, in areas such as the Broughton Archipelago and Johnstone Strait (Figure 1).

Figure 1: Location of Salmon Farms in British Columbia



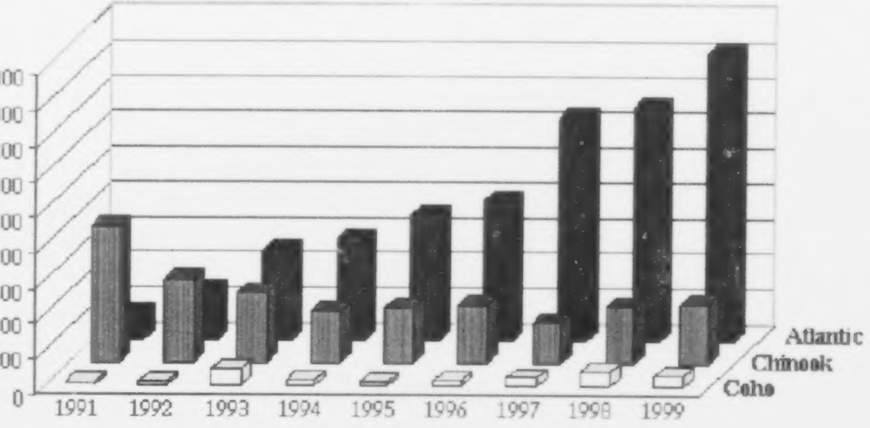
Source: Fisheries and Oceans, Pacific Region, Habitat and Enhancement Branch (in Desautels 2000, p.30-7)

Nearly all of the production takes place in open net cages in seawater. Only a small portion, mainly experimental in nature, occurs at land-based, closed containment facilities. Smolts are transported to the farm sites for grow out (to mature to marketable adults) from hatcheries where they are reared from eggs. The technology used on the farms has been significantly upgraded over the past decade in such areas as feed conversion efficiencies, fish health monitoring, escape prevention, net management, and predator control.

At present, 70% or more of B.C.'s salmon farm production is Atlantic salmon. This species was introduced to B.C. farms in 1985. Recently, increasing interest has been shown in chinook farming (Figure 2).

Figure 2: British Columbia Production of Farmed Salmon by Species

(round tonnes)



Source: British Columbia Salmon Farmers' Association (in Desautels 2000, p.30-9)

Annual production is approaching 50,000 gross tonnes, with an approximate wholesale value of $320 million per year (statistics for 2000) (Figure 3). Because of weak international salmon prices, production has risen faster than product value in recent years.

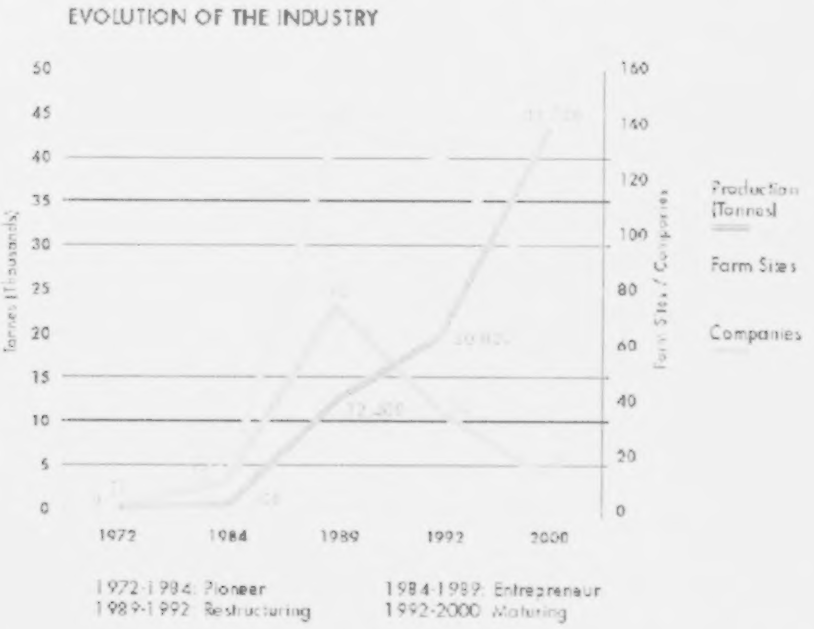


Figure 3: Annual Production

Source: BC Salmon Farmers (www.salmonfarmers.org/industry/development.html)

B.C. produces approximately 3-4% of the world's farmed salmon. Other major producing areas are Norway, Chile, Scotland, and New Brunswick.

Direct and indirect industry employment is estimated at 4,100 jobs. In addition to the farms themselves, the industry includes hatchery operations, processing facilities and feed operations. The industry also provides jobs in support industries such as transportation and veterinary services. Much of the production is exported, the bulk of it to the U.S. market. It is believed that farmed salmon is, in dollar terms, B.C.'s highest value legal agricultural export crop.

On September 12, 2002, the provincial government lifted the moratorium on issuance of new salmon farm licenses which had been in effect for the past seven years. Production had been increasing during the period of the moratorium, from 23.8 million gross tons in 1995 to 49.5 million gross tonnes in the year 2000, as operators increased stocking in the area within their licensed tenures. Industry employment also increased during this time, though not as rapidly as industry production.

Provincial estimates of the magnitude of expansion of the industry are for an approximate quadrupling of production, an additional $1 billion in investment and 9,000-12,000 direct jobs over the next ten years, with 10-15 new farms each year. In addition, four sites are now being relocated and an additional 25 sites are slated to also relocate. New farm sites are likely to be larger than the sites from which tenure holders relocate – some approximating 100 hectares in size. They are also likely to be located farther north along the B.C. coast, toward the vicinity of Prince Rupert (MAFF 2002a).

The regulatory environment in which the industry operates is a complex one, involving many federal and provincial, and some local government agencies. See Appendix 2 of this report for more detail. The main federal regulators are Fisheries and Oceans Canada (DFO) and Environment Canada. Three provincial ministries share primary jurisdiction over the industry. These are the Ministry of Agriculture, Food and Fisheries (MAFF), the Ministry of Water, Land and Air Protection (MWLAP) and the Ministry of Sustainable Resource Management (MSRM).

The provincial and federal governments are currently working to harmonize the regulations that apply to the industry, to enable such things as "one window" permitting for new site approvals.

2 SCIENCE AND RISK: NAVIGATING THROUGH CONTROVERSY AND UNCERTAINTY

The solution to polarization and conflict in difficult environmental management challenges would ideally be convergence of opinion around "the true facts." Unfortunately, our state of knowledge about the potential impacts of salmon farming on wild salmon allows few definitive declarations on where the truth lies. Instead we are faced with partial information, untested theories and much uncertainty. How can we form reasoned opinions and manage salmon farming safely in this context of uncertainty? The starting point is to understand how to interpret scientific information and how to think about risk. This report seeks to explain the science related to impacts of salmon aquaculture on wild salmon and their habitat so that risks can be better understood. To set the stage, this chapter explains aspects of how science works and ways of framing risk analysis.

2.1 How science works: understanding scientific information

Understanding risks posed by salmon farming to wild salmon requires some comprehension of the nature of science and the level of complexity of the subject at hand. Questions of credibility and the relation between science and policy are also explored in the following discussion.

Science, complexity and uncertainty

Science is a structured process of learning based on observation, examination of questions, and reporting. Experimental science presents hypotheses, which are tested through the application of systematic principles of inquiry in specific conditions, times and places. It presents findings that are reviewed and re-tested in other settings. New evidence often alters the research questions as well as the answers. Knowledge is slowly created by a process of observation, deduction and experiment. Scientific progress requires adherence to an agreed method, objectivity in assessment, and the integrity of those involved.

In field biology, results are seldom clear-cut due to natural variation in the environment, so uncertainty is a common feature in results. Uncertainty is not indicative of bad science; it is just the nature of Nature. Natural systems are uncontrolled and inherently variable; ecosystems incorporate complex interactions of environments and animals. Salmon species are a part of these complex natural ecosystems, which are in turn influenced by many human influences, including aquaculture production processes. Others forces that impact wild salmon and their habitat include climate change, hatchery fish, fisheries, freshwater habitat degradation and pollution from various sources. All of these variables are subject to almost constant change. Multiple impacts and interactions are to be expected but are often difficult to understand, especially when there have been limited investigations about how they pertain to salmon farming in B.C.

Even in the most conclusive scientific reports it is important to clearly state assumptions and define the boundaries of the findings according to the specific conditions under which they apply, since most will not apply in all times, places and circumstances. Scale considerations are one type of limitation. For example, the 1997 Salmon Aquaculture Review's (SAR) findings were qualified by the statement "as currently practiced and at current production levels." (Environmental Assessment Office 1997) Production levels at the time of the SAR were roughly half of 2002 levels. Another type of limitation is geographic. For example, National Oceanic and Atmospheric Administration (NOAA) research done in Washington State on Atlantic salmon escapes bears the qualifying statement: "It is imperative to understand that this review pertains to potential impacts in just these two ESUs [evolutionarily significant units] and is not intended to be an evaluation of potential biological risks associated with Atlantic salmon farming anywhere in the world except Puget Sound, Washington." (Waknitz et al. 2002, p.3) Limitations on sample size and data quality are other constraints on the applicability or the level of confidence that may be placed in research results.

How credible is the information we receive?

The information we can access in print, or, increasingly, in electronic formats, is of varying reliability. There are mechanisms that strive to establish quality control, particularly the process of peer review. This is the review of research results by "peers" of the authors – other scientists who could identify errors in the draft results. Most scientific journals require peer review of manuscripts submitted for publication as main articles (as opposed to editorial commentaries, etc.). Consulting and government reports may also be peer reviewed. An example of government peer review processes is Fisheries and Oceans Canada's Pacific Scientific Advice Review Committee, which reviews reports produced by Departmental scientists.

Other sources of information that are less reliable in their scientific rigor include journalistic or media reports, pamphlets published by organizations, and personal opinions offered in correspondence. The strength of information that does not go through peer review processes can be estimated on the basis of the credentials of the writer. What is their depth and breadth of experience? Have they been shown respect in terms of the positions they have achieved or the places in which they have been invited to share their knowledge? Who do they work for? Care must be taken, since the potential exists for results to be shaped to fit the employers' agendas or fund-raising strategies.

"Gray literature" is generally unpublished, and receives limited distribution. Presentations at conferences and submissions to inquiries are examples of gray literature. This literature must be used with caution. In the words of a DFO scientist, "One must always take care in using 'gray literature' but there are times when it is both necessary and appropriate. The source of the material (i.e. an official government publication or a report by a privately funded special interest group) as well as the scientific credentials of the author(s) are important factors." (Noakes 2002, p.6) Similarly, submissions or testimony to inquiries or commissions can vary widely in quality, depending in part on the expertise and background of the person or organization making the submission.

The status of First Nations traditional knowledge is unique. Based in culture and centuries of experience, it operates under different rules than apply to presentation of Western science and experimental results.

This report has drawn on virtually all of the above types of information to build the analysis of the debate around salmon farming and wild salmon. However, at key junctures where facts are being stated or the degree of risk is being assessed, the emphasis is on publications from peer-reviewed journals. Citations in the text lead the reader to a reference section which makes clear the source of the information. The references include the affiliation and/or credentials of the author where these were available in the referenced document.

Science and policy

Science is technical and factual. It informs policy and regulation but it should not (in most cases) dictate policy and regulation. Policy development involves social, economic and political choices, and different methods of information collection and decision-making. Science is one input among several. It can only guide, not direct, difficult decisions in risk management, which are largely value-driven. Therefore, the findings published from scientific research are not necessarily acted upon. Uncertainties may not be accounted for in policy to the extent that the science would recommend, and legitimate differences in scientific opinion may not be documented.

2.2 Framing the analysis of risk

Interactions of salmon aquaculture with wild salmon and their habitats involve the variation of natural environments and incomplete science, leading to significant uncertainty. There are risks – potential, uncertain impacts – to wild salmon associated with salmon farming in B.C. We are thus confronted with the challenges of assessing the risks, determining what an acceptable level of risk is, and finding ways to minimize the sources of risk. Appropriate framing of risk analysis supports informed opinion, as well as informed decisions about risk management, avoidance, precautionary or prevention measures. The purpose of this section is to present some ideas on how to consider risks associated with salmon farming.

Risk assessment

Risk assessment takes into account the probability or likelihood of an event with a negative consequence occurring, and the severity of the consequence. Stated in quantitative terms: "the methodology for risk assessment multiplies the probability of the occurrence by the seriousness of the damage that would result." (Pollution Control Hearings Board 1998)

The results of risk assessment depend on the focus of the questions asked, for example:

- "Risks to what?" e.g. to individual salmon or groups of wild salmon, or to particular species of wild salmon.

- "Risk in what manner?" e.g. by reduction of biodiversity, disease transfer, disruption of migration or spawning behavior, or disturbance of habitat.
- "Risks with what characteristics?" e.g. reversible or irreversible, location-specific or species-specific, seasonal or life-cycle stage related, or related to a level or type of production.

Cumulative effects

Investigations of salmon aquaculture impacts sometimes state, "the risk of harm or impact is low." But we need to ask further, do we know what is the likelihood of a number of 'low risk' situations accumulating, adding up to something higher, as they affect the same fish or group of fish? If risks represent successive opportunities for the same subject, probabilities are cumulative. For example, in a salmon farming scenario, how much do the cumulative risks of multiple farms in an area exceed the risks posed by a single farm in that area?

And further, we should consider the possibility of synergistic effects: might one of these low likelihood impacts interact with one or more others in previously unforeseen ways to bring about unforeseen negative and higher impacts? For example, are fish that are already under stress from water temperature change more susceptible to a particular disease?

Recent inquiries into salmon farming in B.C. have noted, "At present, the cumulative impacts of aquaculture on ecosystems where the majority of farmed salmon originates is unknown" (Standing Senate Committee on Fisheries 2001, p.73), and that "The Department [DFO] is currently unable to assess the cumulative environmental effects of salmon farm operations, as required by CEAA…" (Desautels 2000, p.30-17) However, it appears that DFO is moving to improve its cumulative assessment capabilities (Nener 2002).

Scale effects

A scale effect is simply how the impact of an activity changes as that activity expands. Salmon farming impacts can accumulate as the industry expands via:

- the expansion of the number of salmon farms,
- increase in the size of the farms,
- increase in the stocking levels on the farms, and
- sequential siting of farms along migration routes.

The problem of impacts increasing with the scale of aquaculture has been recognized in Norway: "The Norwegian experience regarding endemic and introduced diseases shows that it is difficult to operate large-scale aquaculture without disease-related problems for wild fish." (Hindar 2001)

Perceptions of risk, and the burden of proof

An industry journalist observed that "One thing that's been consistent in most anti-aquaculture rhetoric is the 'perception of risk,' not that there's proven risk, but there 'could' be a risk." (Chettleburgh 2001) Others with a pro-industry perspective have alleged that that perception of risk is fueled by sensational media accounts, that environmental organizations should assume some of the costs of the research which they call for, and that salmon farming opponents will continually conjecture low probability risks to invoke the precautionary principle: "it may sound like common sense to the average guy, but it can assume a Luddite-like license to kill a new industry for others." (Campbell 2001)

Those who hold the perspective that the risks of salmon farming may be high say that research to ascertain the risk of negative impacts should be undertaken by the proponents of the potentially hazardous activity. In other words, industry bears the burden of proof. Yet incentive for industry or agencies that promote salmon farming to undertake the necessary research is lacking, since the results could lead to measures that would constrain the industry. The Canadian Environmental Assessment Act assigns some of the burden of proof to industry by requiring an analysis of potential impacts on the environment prior to the establishment of a new salmon farm.

Beginning in 1992, the concept of "the precautionary principle" or "precautionary approach" began to be applied in dealing with environmental issues. Canada became a party to United Nations and other international codes and conventions calling for measures to minimize or avoid environmental damage, even in the absence of full scientific certainty. The precautionary approach has also been incorporated into numerous Canadian government documents, including DFO's Aquaculture Policy Framework, the Oceans Act and the Oceans Strategy. Appendix 1 to this report lists many of the applications of the precautionary approach and illustrates the lack of agreement on how the approach should be applied in specific cases. Within DFO, there has been ongoing debate about the appropriate application of the precautionary approach to fisheries management issues (Richards and Maguire 1998, and Fisheries and Oceans Canada 2002b).

What level of risk is acceptable? – the precautionary principle

Values and interests strongly influence the level of acceptable risk. Accordingly, assertions of what is acceptable vary widely. Those who wish the industry to expand and grow claim that risk is decreasing as industry improves its practices, and that current allegations of risk are exaggerated. They suggest that industry activity should proceed in the present production mode (net cages) until such time as negative impacts can be proven. Summarizing presentations at an industry conference in 2000, the Commissioner for Aquaculture Development stated: "'Sustainability' and the 'precautionary approach' are essentially buzz words that will have as many definitions as the number of people sitting around the table. Therefore, these notions are useless in the real life of decision-makers because they do not refer to precise standards, precise objectives or precise deliverables. ... What is really needed is risk assessment, risk management and risk communication." (Bastien 2000)

At the other extreme, some take a "zero tolerance" posture, saying that no salmon farming should take place in the present mode or in certain locations unless it can be clearly shown that no negative impacts will result. Some First Nations and the State of Alaska take this position (KTFC 2002, Alaska Dept. of Fish and Game 2001).

Those calling for better knowledge of impacts prior to expanding (or supporting) salmon farming espouse "the precautionary principle." The precautionary principle and approach have many definitions, varying in length and complexity. A sample of definitions of and pertinent viewpoints on the precautionary principle and approach is presented in Appendix 1. Although Canada is committed to apply the precautionary principle as a result of its participation in a number of international conventions and agreements, the manner of application is still being worked out at the federal level (Government of Canada 2001). Departmental applications of the principle must be made in the context of the overall federal policy direction and guidance, which is currently being prepared by the Privy Council Office (DFO 2002b). Furthermore, the precautionary principle is not the only principle that guides departmental policy. For example, although Canada's *Oceans Act* specifies that the precautionary approach shall be used, *Canada's Ocean Strategy*, released in 2002 (DFO 2002a), which implements the *Oceans Act*, includes the precautionary approach as one of three guiding principles.

A representative of the North Atlantic Salmon Conservation Organization, in a presentation on reducing the risk of aquaculture to wild salmon, set out seven questions which help to apply the precautionary approach:

1. Have the needs of future generations been considered?
2. Will changes that are not potentially reversible be avoided?
3. Have undesirable outcomes and measures that will avoid or correct them been identified?
4. Can corrective measures be initiated without delay?
5. Will the corrective measures achieve their purpose promptly?
6. Has priority been given to conserving the productive capacity of the resource?
7. Has there been an appropriate placement of the burden of proof? (Windsor 2000, p.75-76)

Effectiveness of mitigation

The potential impacts of fish farms on wild salmon will be higher or lower depending on the effectiveness of the efforts to minimize these impacts. Risk management involves the level of technical effectiveness of the preventive measures, combined with the level of adoption or implementation of the measures. For example, in terms of technical effectiveness, vaccines may be more or less effective at preventing disease; biosecurity measures may be more or less successful at stemming the spread of disease; and cage technology may or may not advance sufficiently to prevent escapes. Level of adoption of preventive measures is in turn affected by access to the technology, perceived or actual costs and benefits, and by regulation, monitoring and enforcement. Thus, culling of diseased fish to prevent the spread of viruses, fallowing to prevent the spread of parasites, and tagging of farm fish to identify escaped salmon are not uniformly implemented because these measures have an economic cost to the industry, and there are no regulations to require them.

This report describes ways that negative impacts or threats associated with the various issues could be reduced, but it does not examine the actual effectiveness of measures to mitigate impacts of salmon farming on wild salmon.

Does irreversibility change the rules?

Proponents of risk management argue that the appropriate response to situations in which risk is present is to apply laws, regulations and management practices in the most effective way to mitigate or minimize the risks. This was the focus of the Salmon Aquaculture Review (SAR) recommendations (Environmental Assessment Office 1997). While this is accepted as appropriate in many instances, there is disagreement about whether risk management is an acceptable response to situations in which the risks are of irreversible change. It is a widely-held view that "the highest level of risk arises from potential impacts that, once manifest, are irreversible." (Paone 2000, p.11) In such cases, some argue that actions that pose risks should be entirely avoided or that the source of risk should be eliminated (Carter 1998).

Salmon aquaculture as one of many risks to wild salmon

Salmon aquaculture is only one of a number of potential impacts on wild salmon and their habitat. A senior provincial official noted that: "scientific data does not suggest fish farms are in any way associated with the recent decline in wild salmon populations. Most likely, … the decline has been caused by changing ocean conditions, overfishing, pollution and loss of habitat." (Graham in Rose 2002) Others have pointed to natural shifts in climate, global warming, overfishing and the impacts of hatchery fish (Noakes et al. 2000, p. 381) and to " hatcheries, harvesting, hydro and habitat – the '4 Hs' of threats to wild salmon." (Lackey 2001) Some allege that salmon aquaculture is being unfairly singled out as harmful to wild salmon and their habitat, either because it is new and unfamiliar, or because it is more readily dealt with by policy and regulation.

Others maintain that it is appropriate to carefully assess the risks posed by this relatively new activity before allowing its expansion. The fact that salmon farming may add an additional pressure to wild salmon stocks already impacted by factors such as habitat loss is cause for concern. In theory, if salmon farming presents a low risk to a wild salmon stock when that stock is abundant, this risk may be of greater concern when the stock is at low abundance or productivity. This viewpoint supports adherence to the precautionary principle.

Values, costs and benefits

Values, costs and benefits ultimately determine what level of risk is acceptable, how risks will be managed, whether a "zero tolerance" approach will be taken, how the precautionary approach will be interpreted and which potentially harmful activities most require mitigation or prevention. The complex question of "whose values, costs and benefits?" has cultural, generational, philosophical, legal, economic and political dimensions. Ethical considerations arise if benefits accrue to one set of interests while costs are born by others. First Nations are often used as an example of communities that stand to gain from employment opportunities from aquaculture, but they could also be said to have the most to lose if higher estimates of the negative impacts of the industry are realized (Schafer 2002). The Musgamagw Tsawataineuk Tribal Council testimony to the Leggatt Inquiry stated: "Our greatest fear … is that the wild stock will be destroyed." (Leggatt 2001, p.15)

Some values have legal status – for example, the First Nations right to fish for food, or the protection of fish habitat from "harmful alteration, disruption, destruction" (Fisheries Act, s.35, 36). Rights of salmon farmers to their tenures, established by government decisions, also have value.

It is not surprising that there are no clear answers to questions of risk. Values, costs and benefits largely have to be weighed in political processes, and to some extent in the courts. These decision-making processes nonetheless benefit from the clearest possible scientific understanding of the risks under consideration. Rigorous science, credible analysis and awareness of gaps in our knowledge base are crucial to good decision-making in an uncertain world. This report strives to help meet these needs.

3 DISEASE ISSUES AND FISH HEALTH

The potential for transfer of diseases from farmed salmon to wild salmon presents some important challenges to salmon farming and wild salmon in British Columbia. The most pressing issues, around which this chapter is organized, are parasites – particularly sea lice; bacteria, with some focus on furunculosis; and viruses, especially infectious hematopoietic necrosis (IHN).

The choice to focus on parasites, bacteria and viruses is driven by the level of attention and controversy that have surrounded them, and by their relevance to wild salmon. Other salmon farming health issues have fewer implications for farmed-wild salmon interactions – for example, fungi.

Before proceeding into the issue analysis, some guidelines for understanding disease dynamics are offered. These "rules" are critical to the determination of risk. For example, the multi-faceted phenomena of susceptibility and stress can render a pathogen either harmless or lethal. Seemingly simple principles such as the need for a pathogen to be present in order for a fish to be infected have complex implications.

3.1 The nature of disease in salmonids

Many factors influence disease occurrence and pathogenicity. The development of a disease condition from an infection, and its severity, results from the interaction of the environment, the host and the pathogen. This section discusses six principles important to the understanding of disease dynamics.

Different species are susceptible/resistant to different diseases.

Salmonids are susceptible to a number of bacterial, viral and fungal diseases, as well as parasites, but different species of salmon have different susceptibility to diseases due to genetic differences. Even within a species, different stocks or strains of fish can vary in susceptibility to certain pathogens (St-Hilaire et al. 1998).

Natural populations are selected for resistance to particular pathogens encountered in their environment (Bakke and Harris 1998). In contrast, organisms cultured in new geographic areas – such as Atlantic salmon in the Pacific – lack innate resistance to diseases that have less impact on the indigenous species (Kent 1998a). Nevertheless, by the early 1980s and contrary to expectations, experience in the U.S. Northwest had shown that Atlantic salmon were superior to Pacific salmon for culture, including in the area of resistance to certain infectious disease (Nash 2001).

Susceptibility is affected by life stage.

Many factors cause changes in the immune systems of fish. The main ones are associated with life stage and stress – whether environmental or farming-related.

In species like salmon which spend part of their life in freshwater and part in saltwater, different causes of mortality can be attributed to different life stages and water types; e.g., the transition from freshwater to saltwater (smoltification) can be stressful. The fact that salmonids return to their natal streams can protect them from pathogens that they might be less tolerant of in unfamiliar streams. Younger (juvenile), smaller fish tend to be more vulnerable to disease – especially viruses, but the response to different pathogens in relation to life stage may vary. Furunculosis, for example, appears less pathogenic to parr and smolt than to adult fish, although it is still dangerous (Bakke and Harris 1998).

Susceptibility is affected by stress factors.

Stress is important because infection with a pathogenic microbe is generally insufficient to result in disease. However, when stressed, fish produce certain hormones and blood cortisol concentrations which suppress the animal's immune system, providing an opportunity for pathogens to multiply. This increases the risk of disease for each individual salmon, and provides a mechanism for rapid transmission of infection once some fish become diseased or infectious (Stephen and Iwama 1997, Bakke and Harris 1998, Paone 2000).

Sources of stress for farmed and wild fish are explained in sections 3.5.3 and 3.5.4.

Pathogens have a range of characteristics.

Some pathogens pose a more significant risk of disease than others. Characteristics of pathogens that help determine the risk of disease to fish include virulence, exposure doses required to initiate an infection, contact time required to initiate infection, ability of the pathogen to survive and/or multiply without a host present, and the route of transmission (St-Hilaire et al. 1998). These factors are in turn influenced by other factors. For example, temperature and aspects of water quality such as salinity and organic matter affect the length of time a pathogen can survive without a host. Bacteria can survive and replicate in the environment without a host, but viruses require the presence of a host.

Some pathogens have direct life cycles while others require alternate, intermediate, or transport hosts. Some pathogens can kill fish only as a secondary pathogen exploiting weakened hosts (Bakke and Harris 1998).

Pathogens can be transmitted in a variety of ways.

Disease can be transmitted from fish to fish, by other carriers such as sea birds or by pathogens that are waterborne and may infect animals in their path. Some pathogens need an intermediate host. In relation to fish culture, potential sources of infection include: infected hatcheries, wild fish, escaped farmed fish and processing blood water. Equipment that has come into contact with infected fish can transfer infection between areas. Pathogens of farmed salmon can be shed into the water column or into sediments. The survival time of shed organisms will vary with the microbe and environmental conditions (Stephen and Iwama 1997, Morton 1995). As well, the pathogens become diluted when traveling in tides and currents.

The means of transmission listed above are all forms of horizontal transmission. Vertical transmission occurs when the pathogen is passed from one generation to its offspring, via the egg.

Fish must be exposed to the pathogen to acquire the associated disease.

Salmon can only carry pathogens to which they have been exposed. For "effective contact" or transmission, pathogen and susceptible host must be present at the same time and location. The duration of exposure has to be sufficiently long and the host sufficiently close to the pathogens for infection to be likely (and the host has to be susceptible, as discussed above). For a fish population to be affected, as opposed to just individual fish, a sufficient portion of the population has to be susceptible and exposed to the pathogen.

Higher concentrations of pathogens, as can occur in the relatively crowded conditions of salmon farms, can increase the risk of infection and disease. Conversely, the generally wider dispersion of fish in the wild (except at certain life stages) works against the spread of infection and disease occurrence. As pathogens become dispersed in seawater due to tidal mixing, this too reduces the likelihood of exposure.

Fish can come into contact with pathogens without becoming infected, can be infected without becoming diseased, etc.

A key concept in understanding fish health is that infection is not the same as disease. The resistance of the host is key, as discussed above. Related (and interrelated) principles are as follows:

- A fish may be exposed to a pathogen but not be infected if the pathogen is unable to enter the host fish.
- The host may eliminate the pathogen. Antibodies in wild salmon may indicate that they have dealt with a pathogen through their immune response systems.
- The pathogen may be carried in the fish at some concentration without the salmon itself being infected.
- The pathogen may enter the fish but not be virulent enough to cause disease. The fish may have the ability to adjust to it, which is common in the case of healthy carriers.
- Once a fish is infected, the pathogens may have sub-lethal effects that do not cause immediate death, but weaken the fish. Bacteria will often not cause disease when they enter a fish unless the fish has already been impacted by other factors (Brackett 2000). Parasites, too, commonly have sub-lethal effects on their hosts.
- A diseased fish may be more susceptible to secondary infections, which can cause death.
- Individuals in a population of fish (e.g., a run of salmon) may become diseased, and even die, without affecting the overall health of the population.

The factors that influence disease occurrence interact.

The above factors combine to result in disease outbreaks as follows: the number of cases of a disease increases with an increase in the number of susceptible individuals in the population, and when there has been effective exposure of the susceptible individuals to infectious individuals or the pathogen in the environment.

This means that for farms to cause disease outbreaks in wild salmon, the number of susceptible individuals or the probability of contact have to increase. Aquaculture cannot increase the number of susceptible wild salmon (unless susceptibility is influenced indirectly, such as via sea lice), so the focus falls on the effectiveness of the transmission of disease agents. Farms may load an area with pathogens but there can nevertheless be a low probability of contact. Susceptible wild salmon have to be present, and the contact has to be effective to cause an outbreak (Stephen, pers. comm. 2002).

Causality of disease transfer is difficult to establish.

Associations between factors or events are often mistaken to mean that one factor is causing the other. Kent (2002) recently advised those concerned with disease transfer issues in salmon farming to be careful not to draw connections between phenomena that may be coincidentally related but are not causally related. It is possible that fish population fluctuations that coincide with disease outbreaks can be caused by other factors. Ocean survival rates are often difficult to explain, and the size of salmon runs can fluctuate in unison despite large differences in the characteristics of their home watersheds. Conversely, circumstances within and between watersheds can also be pivotal – such as flooding or low water levels with high temperatures. Environmental conditions can variously allow pathogens and/or salmon populations to flourish. Any of these processes can occur in a synchronized manner with events on salmon farms, and yet be unrelated to those events.

Criteria can be used to establish causes of diseases, such as Hill's Criteria (1965):

1. There is a clear, measurable, statistically significant association between the exposure and the disease (Strength of Association).
2. The association between the exposure and the disease has been observed by different persons, in different places, circumstances and times (Consistency of Association).
3. The exposure always produces the disease (Specificity of Association).
4. The exposure closely precedes the disease (Temporality).
5. An increase in exposure produces an increased frequency or severity of the disease (Biological Gradient).
6. The hypothesized causal relationship is biologically plausible (Plausibility).
7. The causal relationship is consistent with the known natural history and biology of the disease (Coherence).
8. There is experimental or semi-experimental evidence from other populations that shows the same relationship (Experimental Evidence).
9. There is a similar known relationship involving another disease or related type of exposure (Analogy).

Bakke and Harris (1998) caution that although causation is difficult to prove, disease potential stemming from situations that do not meet these criteria should not be ignored. They note that Hill's criteria cannot be met either for the spread of furunculosis or for the epidemic of *Gyrodactylus salaris* in Norway, and that in the latter case, this failure could have contributed to the slow response to the emerging problem (see Section 3.5.1).

Currently, there is strong circumstantial evidence for the transfer of sea lice from farmed to wild salmon, and several, but not all of Hill's criteria have been met (see Section 3.2.5).

Rough correlations should not be used to justify costly research or preventive and/or mitigative measures. However, it is appropriate to use suspected causality as a basis for action – or at least a precautionary approach – when the association shown by reliable data sets is strong. Even Sir Austin Bradford Hill, the author of the criteria, offered a cautionary note: "All scientific work is incomplete – whether it be observational or experimental. All scientific work is liable to be upset or modified by advancing knowledge. That does not confer upon us a freedom to ignore the knowledge we already have or postpone the action that it appears to demand at a given time." (Hill 1965) Ideally, the accumulation of observed correlations should be examined and follow-up questions should be framed. Then experimentation and further research can be undertaken to firmly determine cause and effect.

3.2 Parasites, particularly sea lice

3.2.1 Parasites and salmon

Parasites of concern to salmon farming include helminth parasites (parasitic worms) and crustacean parasites. Crustacean parasites are currently of predominant concern because they include the Family Caligidae – caligid copepods, or sea lice.

Kudoa thrysites is a type of myxosporean parasite that is relatively non-pathogenic, and seldom causes mortality (Kent 1998b). Kudoa (also known as "soft-flesh syndrome") has economic consequences since it affects the quality of the flesh of farmed salmon as they go to market. Very little is known about the biology of the parasite, but it does not appear to pose a risk for transfer from farms to wild salmon. It occurs naturally in several wild species of fish and seems only to pose a challenge to fish in the conditions of a fish farm.

The only parasite that appears to be significant in the context of transfer from farmed to wild salmon is the sea louse. Critical to the analysis of the debate around sea lice is the fact that detecting the effects of parasitism in wild host populations can be very difficult, especially in juvenile fish populations from which dead and diseased individuals may rapidly disappear.

In comparison with bacteria and viruses, parasites typically have lower reproductive rates with longer generation times, are more persistent but with less lethal infestations, have more stable populations through time, and larger body size.

The nature of sea lice

The sea louse is a small parasitic copepod. The term sea lice is commonly used to refer to several species of marine, externally-parasitic copepods of the Family Caligidae that infect salmonids (Johnson 1998). *Lepeophtheirus salmonis* is the main species of concern. It is limited in its host range to salmonids (while other species of lice have non-salmonid hosts) distributed over the northern hemisphere.

The complex life history of the sea louse (Johnson 1998, MacKinnon 1997, Watershed Watch 2001) determines how salmon become infected. The species undergoes a series of 10 life history stages, with a molt between each stage, taking it from egg to adult. Sea lice carry their eggs in strings attached to the genital segment. Egg production is a continuous process. When the egg develops to the *nauplius* stages it begins free-swimming in the plankton and disperses. It is not infective, however, until it reaches the *copepodid* stage when it becomes able to attach to the salmon. The louse can only survive in its free-swimming stage for 2 to 8 days (depending on water temperature), as it is not feeding during this period. It must attach to a host within this period to survive and mature. On the host, it develops to the *chalimus* stage, and grows, while anchored on the host, to the preadult and adult stages. At these stages it becomes more mobile on the fish and able to swim, and acute impacts on the host become evident.

Louse survival at most stages is reduced in lower salinities, and it dies when adult salmon enter fresh water. Most lice are lost within 2 days of entering fresh water (McVicar 1998a). The death of sea lice in freshwater is important as it breaks the life cycle of the parasite, leaving none to infect the out-going juvenile salmon in the next spring.

The impact of sea lice on salmon

Disease is caused by the feeding activities of the sea lice, which feed on the mucus, blood and skin of the fish. Lice can cause serious fin damage, skin erosion, hemorrhaging and lesions, which can penetrate deep into the flesh and sometimes to the bone. Death of heavily infested hosts is directly due to dermal ulceration and osmoregulatory failure. Increased stress and/or immune suppression increases the hosts' susceptibility to other pathogens. Pathogens can enter through the lesions caused by the lice. Secondary diseases to which the hosts may then succumb include vibriosis and furunculosis. Thus, the stress caused by lice can weaken the fish without causing mortality; however the various effects of the parasite can contribute significantly to fish loss (Mustafa et al. 2001).

Various factors influence the severity of the impacts of sea lice on fish. In general, the relationship of the number of sea lice to the severity of the disease depends on 1) size and age of the fish, 2) the general state of health of the fish, and 3) the species and developmental stages of the sea lice present (Johnson 1998):

- More lice per fish are generally more pathogenic (causing stress, disease, and death).
- Smaller fish, including juveniles, are at higher risk.
- The development time (length of the life cycle) of the lice is affected by water temperature (shorter when warmer) and species of host. Generation time can be anywhere from approximately 48 to 93 days depending on the sea temperature (Johnson 1998). At 10 degrees Celsius the time period is 7.5 to 8 weeks (MacKinnon 1997).
- The species of the host fish affects susceptibility: Adult male lice take about 15 days longer to appear on chinook salmon post-infection as compared to Atlantic salmon (Johnson 1993 in Watershed Watch 2001). One study showed that pink salmon carry the highest loads (5.8 adult lice/fish on average) and highest prevalence (92%) (Nagasawa et al. 1993 in Watershed

Watch 2001). Coho, the most resistant species, are considered to be less susceptible than either chinook or Atlantic salmon.

- Slower swimming fish are more susceptible. Slower swimming caused by the stress of lice infection in turn leads to higher predation of wild salmon.
- Susceptibility is also affected by the levels of stress a fish is experiencing from other sources.

Because sea lice do not survive in fresh water, it is certain that the smolts put out to the net pens are free of lice. Accordingly, lice are introduced to farm salmon by wild fish.

Sea lice as vectors for other diseases

Sea lice may function as vectors of viral and bacterial diseases, and it has been demonstrated that they can perform this function for the agent of infectious salmon anemia (APHIS 2002). "Whether this route of transmission represents a passive transfer of virus or is due to active replication of virus in the sea lice has not yet been clarified." (Dannevig and Thorud 1999, p.156) The bacterium which causes furunculosis has been found on the surface of *L. salmonis* (Johnson 1998), so sea lice could transfer the disease to migrating salmon. Further, an epidemiological study in New Brunswick showed that the spread of ISA increases as the number of sea lice treatments decreases (as one factor among others) (Hammell and Dohoo 1999 in Whoriskey 2000a).

3.2.2 Points of view on sea lice issues

How harmful are sea lice to wild salmon?

Point of view: Sea lice are usually not that harmful to wild salmon and are naturally common on wild salmon.

Sea lice are very common on several species of wild salmon in the B.C. waters, and after a few months at sea, most wild salmon are host to small numbers of sea lice (BCSFA 2002). Usually though, the abundance of lice and the damage they cause are low (Johnson et al. 1996). Since B.C.'s wild salmon have coevolved with lice, sea lice have generally been regarded as relatively harmless in wild populations.

Point of view: Under certain conditions, sea lice can be very harmful to wild salmon.

Despite their natural prevalence, sea lice are known to be occasionally pathogenic in the wild. In heavy infections, death results from erosion of the skin of the fish, physiological stresses, and/or secondary infections. Other possible consequences for wild fish besides mortality from sea lice include premature return to spawning (as shown with brown trout in Europe) and reduced seawater growth (Hindar 2001).

"The scarcity of lice-associated disease incidents in wild salmon may be due to the generally lower numbers of lice per fish but the possibility that it is only the lightly infected fish which survive and can be sampled should not be ignored. … The apparent rarity of signs of disease associated with infections such as lice should not be taken as indicating they do not have a significant impact on the fish population." (McVicar 1998a, p.3012)

Ultimately, the ability of the fish to survive depends on the severity of the infection. As few as five lice may debilitate a fish of 15 grams or less; 11 or more will cause mortality (Watershed Watch 2001). A Norwegian study by Dr. Jens Christian Holst, of the Marine Institute, checked post-smolts at fjord mouths and found that the surviving fish never have more than 10 adult lice, and those heavily infested are in poor condition and had hardly grown at all. The study also placed wild fish in tanks and found that fish not treated for sea lice were unlikely to survive once the number of lice passed 10 per fish. The study concluded that in years with high lice numbers, this could mean that up to 95% of wild smolts are dying, demonstrating a clear negative population effect on wild stocks from sea lice infestation (*Fish Farming* 2002).

Does salmon farming increase the risk of exposure of wild fish to sea lice?

Point of view: Prevalence and intensity of sea lice might be just as high without the presence of salmon farms.

Few studies have examined the prevalence or intensity of sea lice on salmonids in areas free of aquaculture. Two studies in B.C. have looked at sea lice specifically on wild sockeye salmon. One examined sea lice on adult sockeye returning to the Sproat and Stamp rivers through Alberni Inlet. All of the sockeye examined were infected with sea lice and had higher intensities of lice than previously reported on the high seas. The scientists stated that the high numbers of early developmental stages of the lice suggests a high rate of infection for sockeye in coastal waters. The authors did not associate this with salmon farms in the area. In one of the years studied, delays in migrating into the river systems led to high mortalities as the damage from the lice had time to progress (Johnson et al. 1996). A study conducted in 1971 also found high infestation rates on Fraser River sockeye. A 1964 publication looked at another type of copepod – *Caligus clemensi sp. Nov* – on juvenile pink salmon. (These reports are referred to in Noakes 2002, p.6.) Both of these studies were conducted prior to the start of salmon farming in B.C.

Often it is the higher densities of sea lice on salmon farms that are said to present a significant risk of exposure of wild salmon to lice (see below). In response, industry representatives argue that sea lice infestations are costly to salmon farms (Mustafa et al. 2001) and farmers therefore treat the outbreaks rapidly, killing the lice before they reach dangerously high numbers (Grydeland in Hume 2002). Furthermore, over recent years, better management practices to reduce sea lice occurrence and treating of sea lice outbreaks at farms have improved the situation.

Point of view: The characteristics and location of salmon farms make it more likely that wild salmon will be exposed to sea lice.

Many argue that salmon farms offer ideal conditions for lice to flourish, providing opportunities for migrating salmon to pick up lice as they pass by the farms. The factors involved are as follows.

1) There is no evidence that sea lice are a significant disease factor for wild salmon, in the absence of salmon farms, if the salmon are not under stress:

Results of research published in 1993 on the abundance and distribution of L. salmonis on Pacific salmon in offshore waters of the North Pacific and the Bering Sea contrast with the results of the studies mentioned above. This study found very low intensities of infection on sockeye from sea lice (Nagasawa et al. in Johnson et al. 1996). There appear to be no published studies on L. salmonis infestation on juvenile salmon on the Pacific coast. If sea lice were a mortality factor on juvenile salmon, the mortalities would simply be included in the "black box" referred to as natural mortality during early ocean residence. The Program Manager for Marine Salmon Interactions at the Auke Bay Laboratory in Alaska has stated that infestations of lice on young salmon, although occasionally present, are not normally observed, while infestations on returning adults are common (Heard, pers. comm. 2002).

2) Salmon farms can increase the density of lice, thus acting as reservoirs for lice:

The large number of hosts in the confined area of a net pen (varying widely, but typically 35,000 to 90,000 fish in a pen of approximately 10,000 square feet, depending largely on the weight and size of the fish) can increase the abundance and dispersal of sea lice, increases the likelihood of infective stages locating a new host by direct movement from fish to fish, and elevates the stress levels in fish predisposing them to infection (Bakke and Harris 1998, MacKinnon 1997). Lice populations are thus said to become biomagnified.

3) Many salmon farms are on migratory routes of wild salmon:

Migrating salmon frequently pass close to (and through) salmon farms, with proximity increasing in relation to the density of farms. Lice on the adult salmon on the farm produce copepodids, which can attach to out-migrating juvenile salmon. Juvenile pink and chum salmon may be particularly at risk from farm-related sea lice infestations because: they enter the marine environment at a smaller size than other species of salmon; they remain longer in the near-shore environment before migrating to sea; and the smoltification process increases the fish's susceptibility to sea lice. Johnson (1998, p.83) explains that copepodids gather near the surface during the day, so that salmon are more likely to become infected during daytime when they come to the surface to feed.

4) Salmon farms provide hosts on which sea lice can survive through the winter:

Under natural conditions, sea lice fall off salmon and die when wild salmon enter fresh water to spawn, leaving the parasite deprived of a host. Thus there would not be significant numbers of adult infested salmon in the inlets at the time salmon smolts migrate to the sea. However, the salmon in farms can provide over-wintering hosts for sea lice.

5) Sea lice can easily attach to slow moving salmon in net pens:

Reduced water movement in net pens leads to higher numbers of sea lice, which are relatively weak swimmers (Johnson 1998).

6) Sea lice thrive in the well-lit conditions of the salmon farm:

Copepodid larvae are attracted to light (MacKinnon 1997), and some believe that sea lice grow better in well-lit conditions. The night-lights on salmon farms thus may create an environment conducive to a sea lice outbreak (Living Oceans Society and Morton 2001, Morton 2001a). (Note that Johnson (1998) cautions that attraction to light has been shown in the laboratory but may not apply in the field.)

7) Although salmon farmers treat their stock for sea lice, the lice may still pose a threat:

Lice may be present for periods of time or at certain densities on farmed salmon prior to being treated. It may be possible that some lice are not killed by treatment and are instead dispersed into the seawater.

In Europe, regulations have progressively called for lower concentrations of lice on salmon farms to lessen this reservoir effect. In Norway, only 0.5 louse per farm salmon is allowed in the spring season in order to protect wild stocks (Morton 2001b). Holst, of the Marine Institute in Norway, believes that the salmon farming industry needs to do still more to cut lice numbers in densely farmed areas, aiming for 0.1 adult female lice per fish (*Fish Farming* 2002). A recent paper by Butler (2002) recommends that a target of zero egg-bearing lice will be required on farms to minimize impacts on wild salmonids. A major Scottish review of salmon farming impacts recently concluded that the burdens of lice acceptable to the farmer are higher than the levels probably required to minimize effects on wild fish (Scottish Executive 2002).

Do sea lice spread from salmon farms to wild salmon?

Point of view: Experience in Europe and observations in the Broughton Archipelago provide compelling evidence that sea lice do spread from salmon farms to wild salmon.

Scientific publications have reported statistically significant, geographic correlations between wild salmonids' lice infestations and salmon farms in Europe. Gargan, Senior Research Officer for Ireland's Central Fisheries Board, summarized studies of the impacts of sea lice on wild salmonid stocks in Europe, focusing on the potential relation to salmon farming. He concluded that "The development of salmon farming has dramatically increased sea lice infestation pressure on wild stocks of sea trout and salmon in Norway, Scotland and Ireland" (Gargan 2000, p.45).

Norway:

In a 2001 publication, Bjorn et al. (p.958) conclude: "We … suggest that lice-infected farmed salmon are the main contributors of the increased salmon lice infection in wild anadromous sea trout and Arctic char at the exposed locality." The summary of their study is as follows: "… the present study shows that salmon lice infection on wild sea trout and Arctic char differed significantly between the area close to and the area distant from salmon farming activity. Furthermore, the results from the exposed locality show that high lice infections may have profound negative effects upon [wild] populations of sea trout by (i) reducing fish growth by forcing post smolts to return prematurely to freshwater, (ii) effecting stress responses and physiological disturbances, and (iii) exposing heaviest infected fish to increased risk of mortality. … In the area without salmon farms, no heavy salmon lice infections were recorded and thus salmon lice did not seem to affect the fish stock." (Bjorn et al. 2001, p.959-60)

Even more recently, a 2002 study published by Bjørn and Finstad concluded that fish farming contributes to an elevated lice level in wild fish. This study focused on the infestation level of lice hosts at sea (sea trout and Arctic char) in relation to their previous exposure to salmon farms. The results complemented the earlier studies showing lower lice infestation on wild salmon in bays without farms than in bays with farms by eliminating possible sampling biases related to sampling in-migrating salmon closer to shore.

Ireland:

Gargan (2000) examined lice levels on sea trout at 52 river mouths around the Irish coast and discovered a strong correlation between lice intensity in wild trout and the proximity of salmon farms. Heavy and lethal infestations (more than 30 lice per fish) occurred on wild sea trout post-smolts only near salmon farms. In contrast, wild trout from rivers without salmon farms were not heavily infested. Many sea trout stocks have collapsed in the vicinity of salmon farms. The research ruled out the possibility that infestations originated from wild salmon populations.

Tully et al. (1999, p.41) reported on a study investigating infestations of post-smolt sea trout by the salmon louse in 42 estuaries over a 5-year period in Ireland: "Significantly higher infestations occurred in bays that contained lice-infested farmed salmon. Lice-infested wild spring salmon, which were present in estuaries of some systems, did not have a significant positive impact on infestations."

Tully and Whelan (1993) suggested that 95% of lice observed on wild sea trout off the west coast of Ireland in 1991 might have derived from local salmon farms.

Scotland:

In a study by Butler et al. (2001), analysis of three years of data from five rivers demonstrated that inter-year variations in infestations were related to salmon farm production cycles in the local area. The study also showed that the abundance of lice on sea trout was significantly higher in areas with mixed year class production than in areas of single year class production, due to the more continuous presence of egg-producing female lice in the former areas. "The acute burdens in mixed year class areas were also reflected by the lice population structure, in which juvenile stages (copepodids and chalimus) predominated, and mobile stages (preadults and adults) were relatively scarce. In single year class areas the demography was more balanced ..." (Butler et al. 2001, p.18)

The Fisheries Research Service of the Scottish Executive released results of a new study at the October 2002 conference of the International Council for the Exploration of the Sea (ICES) in Copenhagen. The study found that every second year, when the fish farms are in their second year of production and large fish are present in the cages, large numbers of sea lice were present in spring at the time when sea trout smolts go to sea. In alternate years, when fish farms are in the early stages of production, the sea lice did not build up (Ross 2002). These results were reported in two presentations at the ICES conference (McKibben and Hay 2002, Penston et al. 2002).

The Scottish Executive, in its 2002 *Review and Synthesis of the Environmental Impacts of Aquaculture*, concluded as follows: "Wild salmon and sea trout are at risk from infective larval sea lice that may be associated with Marine salmon farms."

Europe in general:

The European Commission (2002) has recently concluded that "The reduction of wild salmonid abundance is also linked to other factors but there is more and more scientific evidence establishing a direct link between the number of lice-infested wild fish and the presence of cages in the same estuary."

Broughton Archipelago:

Since 2001, questions surrounding sea lice, salmon farming and wild pink salmon infestation by sea lice in the Broughton Archipelago have been the subject of much debate. Many feel that there was a major impact on wild pink salmon by lice transferred from salmon farms in this area. Others do not believe there exists sufficient evidence to support this claim.

Sampling of juvenile pink salmon by a local biologist suggested that there was a major outbreak of sea lice in the Broughton Archipelago in 2001 as a result of salmon farms. Morton undertook sampling to examine the magnitude of infestation of migrating juvenile pink salmon by sea lice from June to August 2001. Pink fry were sampled at 5 sites where they had yet to encounter a salmon farm, and at 60 sites where they may have been directly exposed to salmon farms. Abundance and prevalence of lice, and numbers of lice per fish (per gram of weight) were all significantly higher in juveniles directly exposed to salmon farms than in juveniles that had not yet encountered a salmon farm (Morton, pers. comm. 2002).

In contrast, a government survey did not establish evidence of an outbreak of sea lice in the Broughton Archipelago in 2001.The Department of Fisheries and Oceans and MAFF conducted two studies of juvenile salmon of various species in the Queen Charlotte Strait area in June and July 2001(DFO 2001). A trawl survey was used to study the rate of infestation of sea lice in the area immediately north of the Strait of Georgia. This was supplemented by a seine survey in the Broughton Islands. The purse seine survey caught very few pink salmon smolts in the area of concern. The study found that 78% of juvenile pink and chum salmon were infested with 2 or fewer sea lice (all stages). The MAFF and DFO concluded on the basis of this survey that there was no correlation between levels of infestation of juvenile pink salmon and salmon farms in the area (van Dongen 2002).

Much of the controversy which has followed the two studies described above relates to sampling methods. Standard sampling gear and techniques are essential for allowing replication of observations across space and time by different parties. The government survey met this principle (Noakes 2002, Rahn 2001). However, the timing and location of the government survey, and the suitability of the gear used, have been called into question (GSA 2002, Orr 2001, Simpson 2001, Frazer 2002, Musgamagw Tsawataineuk Tribal Council 2002, Morton, pers. comm. 2002). Questions were also raised about Morton's approach, to the effect that dip nets may have selected for the weaker, impacted fish by missing the healthier fish that would not have been found in shallow waters. Rebuttals to this point explain that juvenile pink salmon naturally swim near the surface prior to out-migration.

Notwithstanding the need for a scientifically-proven, carefully planned and replicated approach to sampling, it can be argued that latitude should be allowed for capturing data on novel events: "it is the anomaly that has been the true driving force for new science and not hypothesis testing and rigorous statistics." (Parsons 1985, p.109-110) The debate over sampling techniques in the Broughton tends to cloud the fact that there was an exceptional observation of sea lice prevalence in the areas of dense salmon farming. The Broughton Archipelago has the highest density of salmon farms in B.C. It is also a major natural production area for all Pacific salmon species except sockeye. Several observers believe that these factors combine to make the salmon farms a source of lice for the pink salmon, and that our knowledge about the life cycles of lice and salmon combined with Morton's research support the connection.

The pink salmon alleged to have been infested with lice on their out-migration were due to return in the summer of 2002, but returns in the area were very low: "There appears to be a near-total collapse of seven pink salmon runs in B.C.'s Broughton Archipelago … Results from seven of Broughton's rivers to date show a dramatic shift from 3.6 million fish in 2000, the 'brood' year for these runs, down to 57,220 this year, a drop of more than 99%. Some rivers have seen no pink returns." (Living Oceans Society and Raincoast Research 2002) Records show that 2002 is the first year with significant declines in all 6 major rivers simultaneously, and there has never been, since records have been kept, such a dramatic crash. This crash is limited to the portion of the coast in which fish farms are located (McCue 2002). Morton (pers. comm. 2002) notes that good returns were experienced at the one river at which her sea louse survey recorded uninfected juvenile pinks.

After the research for this report was completed, a consultation meeting was hosted by the PFRCC on the issue of low pink returns in the Broughton Archipelago (on October 28, 2002 in Campbell River). Numbers of fish presented at that meeting differ from those above, but the analysis presented at the meeting by DFO scientists pointed to the cause of the low returns as originating in the near-shore environment during the spring and early summer of 2001, when pink salmon fry were migrating out of the mainland inlets (PFRCC 2002). These were the areas in which Morton found high levels of lice infestation at that time.

For context, it is notable that the interception fisheries in the archipelago were eliminated in the 1970s, and the outside fisheries were closed in the 1990s. Despite these measures, the fisheries have not rebuilt. It is also worth noting that sea lice problems in Norway and Ireland also took a number of years to materialize.

Point of view: Causality in the spread of sea lice from farmed fish to wild fish in British Columbia has not yet been proven to the highest standard of scientific scrutiny.

There is no proven, direct link in the spread of sea lice from farmed fish to wild fish in British Columbia, or that the presence of farms has increased sea lice levels or contributed to outbreaks (BCSFA 2002). Similarly, there is no evidence that Puget Sound salmon farms cause the spread of salmon parasites such as sea lice (Pollution Control Hearings Board 1998).

In reference to the Broughton case, Odd Grydeland of the BCSFA argued "Salmon farms have been in that [the Broughton] area for 17 years and the wild salmon have been thriving." (Hume 2002) Industry and others thus assume that factors other than salmon farms account for the higher numbers of sea lice. Alternative, speculative explanations that have been put forward for the high numbers of sea lice on the wild fish sampled by Raincoast Research include: environmental conditions may have allowed sea lice to proliferate that year (Noakes 2002); the fish may have already been stressed by other causes: "High water temperatures and high salinity levels resulting from a warm, dry winter exacerbated the situation [since warmer water temperatures favour lice while stressing fish]" (Living Oceans Society and Morton 2001); lice may have reproduced on the out-going pinks (Groves 2002); and large pink salmon populations presented a potential reservoir for lice (Noakes 2002).

3.2.3 What can be done about sea lice in relation to netcage salmon farming?

The most comprehensive approach to controlling sea lice in salmon farming is called integrated pest management. This approach includes: pest identification, management for prevention, monitoring farm populations and damage, reducing pest populations and optimizing therapeutic treatment (Morrison 2002b).

Prevention

There has been research towards producing a vaccine that will prevent development and survival of sea lice (MacKinnon 1997), but no effective vaccine is so far available. Research in this direction is continuing, and some experiments support the view that development of a vaccine for sea lice is possible (Johnson 1998).

Salmon strain selection may be another way of enhancing resistance of farm salmon to sea lice.

Preventive techniques that can be used now include: clean nets, fallowing (at least 3 months), single-year class net pens, appropriate siting (avoiding migration routes), healthy smolts, and lower fish densities (fewer fish per pen). Some of these are further described below. Other measures to generally promote the health of farmed fish are discussed in Section 3.5.3.

Siting farms away from risk factors

To reduce the chances of farm fish exposure to lice, sites should be located in areas where currents carry away the infectious copepodid stages, and away from areas with abundant wild hosts, including within or near wild salmon migration routes. "Other known factors affecting sea lice biology should be considered when choosing a site, including the known effect of decreased water temperature and decreased salinity on growth, development and survival (Watershed Watch 2001).

Fallowing

Experience in Europe has shown that the most effective way of reducing lice infestation and its impacts on wild stocks is whole-bay fallowing in the spring (Gargan 2000), which breaks the lice life cycle – the infective stage dies out before new hosts can be infected. At a minimum, the duration of fallowing should cover the life cycle of the parasite from the egg stage to the maximum time of *copepodids* (at least 30 days during winter months (Watershed Watch 2001). In B.C., some fallowing is done on a farm-by-farm basis between production cycles to ameliorate environmental concerns at specific farm sites. To use rotational fallowing to take precautions during the production cycle, more sites would need to be available than are used in production pens.

Single age classes

Keeping only fish of the same age at a farm site is based on the observation that newly introduced smolts are more susceptible to infection by sea lice than other age classes of fish. The practice thus avoids re-infection of farms by adult carriers of lice passing them on to juveniles. This is especially effective for *L. salmonis* which do not move from fish to fish during the pre-adult and adult phases the way certain other sea lice can. Single age or year class stocking of inlets is one of the preventive measures required in Norway. It has also been shown to be effective through experiments, and in experience, in Scotland.

Single bay management

Various health management techniques are most effective if they are practiced simultaneously, by all farms operating in a bay or channel. Coordination can make the efforts of each individual farm more effective. Unless only one company operates in a given bay or channel, the companies operating within a bay must share information on infections and management.

In Ireland, a single bay management initiative, established in 1997, is based on simultaneous lice monitoring on farmed salmon and wild sea trout. In Scotland, wild fishery and aquaculture interests on the west coast are forming voluntary Area Management Agreements to promote the coordinated management of lice on farmed and wild salmonids (Butler et al. 2001, p.3).

Non-chemical methods of lice control

In Norway non-chemical methods of lice control, such as "cleaner fish" – wrasse – are widely used and experiments are underway in Scotland (Scottish Executive 2002). According to Whoriskey, experiments in North America suggest that cleaner fish would not be effective here. "In addition, aquaculturists run the risk of introducing diseases to their cages by the addition of wild fish whose disease histories are unknown." (Whoriskey 2000b, p.34) This could be exacerbated in B.C., where there are no native species of wrasse. In contrast, EVS Consultants (2000) report an interest in this option in British Columbia, where several fish species have been identified as having the potential for acting as cleaner fish.

"As with all lice control methods the use of wrasse has limitations but it can be used to reduce the use of chemotherapeutants …" (NASCO 1995).

Lice control with chemotherapeutants

Because of the reservoir of infection in the natural environment and the fallibility of preventive measures, it is likely that there will always be a need for the regular use of lice control therapeutants in farms.

Available treatments

A great deal of effort has gone into the development of treatments for sea lice (Johnson 1998). In B.C., some on-farm experimental trials were undertaken to test the use of external application of pesticides, through baths. A bath treatment reduces the volume of the net pen with an underlying tarp that is drawn up around the net pen, and then adding chemicals to the water. After treatment, the water is released to the environment. Bath treatments are costly, may cause physical damage to the fish, and have associated high levels of stress. Therefore, oral treatments for sea lice are preferred, and treatment in B.C. has been through feed rather than chemical baths.

Currently in B.C. there are two products available to farmers for sea lice: ivermectin and emamectin benzoate, also called SLICE. Both are administered to the fish in feed. These products are available to farmers by veterinary prescription only and are regulated.

Ivermectin is a licensed prescription product widely used to manage parasites on domestic and farm animals, and can also be used on humans. It has a long withdrawal period (about 3 months) prior to harvesting, which also minimizes the need for repeat doses. The manufacturer does not recommend it for use in fish (it is used "off-label"). With the advent of new products such as SLICE, with shorter withdrawal periods, the use of ivermectin has decreased.

Emamectin benzoate (SLICE) is a relatively new chemical that appears to be effective but less toxic than ivermectin to some fish and non-target species (Mustafa et al. 2001). Emamectin is in the process of being licensed by the Bureau of Veterinary Drugs, Health Protection Branch, Health Canada. In the event of an emergency problem, the Bureau of Veterinary Drugs allows the use of products that are in the process of being licensed, yet have not received final approval, through the Emergency Drug Release (EDR) program. Scientific information available internationally indicates that "SLICE is a safe and effective product for fish and poses minimal risk to the aquatic environment." (MAFF 2002b)

Secondary environmental effects of therapeutics

Ivermectin persists unchanged in fecal materials in residues under the net pens, and laboratory studies indicate some possible affects of ivermectin on crustaceans. MAFF nevertheless asserts that there is no evidence to indicate that its use in salmon feed has had an impact on the environment. Given judicious use and precautions to reduce the risk of loss of feed into the environment, the risk of impact is claimed to be low (MAFF 2002b). Nevertheless, there is widespread concern about the potential impacts of lice treatments on the environment. This report examines the potential impacts of chemicals from salmon farms on wild salmon in Section 5.2.1.

Other limitations of chemotherapeutants

Concerns around chemotherapeutants in addition to environmental effects include availability, costs, and fish loss due to treatment stress and withdrawal period. The availability of only a few treatment agents means that the lice become resistant, reducing the effectiveness of the limited group of medicines (Scottish Executive 2002). The cost of producing farm salmon increases, with current treatments costing an additional $0.13 to $0.18 for each kilogram of salmon produced (Mustafa et al. 2001).

The environmental and practical limitations of chemotherapeutants suggest that they will not be the main, ultimate solution to the lice problem on salmon farms. According to a scientist who examined the economic costs to farming of lice and lice treatments, until a vaccine or more effective treatments are developed, the focus should be on better husbandry methods, such as fewer fish per net pen, separating year classes, and fallowing. As well, the development of sea louse-resistant strains of salmon, immunomodulating feed, and improved land-based farming should be explored (Mustafa et al. 2001).

3.2.4 Gaps in our understanding of issues related to sea lice

MacKinnon (1997, p.6) argues that commercial and environmental implications provide "a compelling need" to demonstrate conclusively, with a method other than observation and presumption, whether sea lice from fish in net pens are infecting wild salmonids that swim close to aquaculture sites. Various scientists and organizations have called for research to bring greater understanding of the mechanisms by which farmed fish become infected with sea lice from wild populations and from other farms, and by which wild fish become infected from farm sources. McVicar (1998a) feels that much of the controversy over the extent of the contribution of lice from farmed salmon to wild fish populations can be attributed to an inadequate database. He highlights the lack of: historical (pre-fish farming) data on lice levels in wild salmon populations, recent time-series on fish farms, spatial variations in lice levels, and the pathogenicity of lice to salmon for wild populations.

A focus of effort on achieving a reduction of farm lice levels and on understanding the biology of transmission of infection to new hosts could maximize the benefits of investments in minimizing the risk of transmission (McVicar 1998a).

Most studies of sea lice infestations of wild fish have been undertaken in Europe, and most of these have focused on returning fish. This could lead to a sampling weakness, in that the presence of lice may make fish return earlier, and thus the fish sampled would carry a disproportionately high burden of lice. Out-migrating smolts and adult fish may also suffer significant mortality from lice but they are difficult to sample. Bjørn and Finstad's 2002 study partially fills this research gap by focusing on the infestation level of lice hosts at sea.

The Centre for Aquaculture and the Environment at the University of British Columbia is undertaking a group of studies that deal with the role of farm sites in sea lice infestation rates among wild fish and the treatment of infested fish at farms (McKinley 2002). Researchers funded by the David Suzuki Foundation are doing surveys to explore the distribution of lice in B.C. waters in areas with no salmon farms as compared to areas with salmon farms.

Specific topics of research that have been suggested to fill gaps in our knowledge related to sea lice include:

- baseline information on rates of sea louse infestation in non-farm areas, and the natural prevalence and intensity of sea lice in wild salmon at the sub-adult stage in particular (juvenile Pacific salmonid susceptibility);
- experiments (e.g. put caged fish at different distances/depths or other locations in relation to fish farms) to assess transfer of infection and specific modes of infection;
- the mode and rate of transmission of the infective stages of lice from farms, including lice burden on farms and separation distances between migratory fish routes and fish farms;
- the role of sea lice as vectors for the transfer of disease;
- identification of lice originating from farmed fish, e.g., through genetic markers, morphological differences, stable isotopes and fatty acids related to diet;
- response (behavioural, physiological) of different native species of Pacific salmon to sea lice;
- the genetics of salmon and lice to evaluate strain effects and co-evolution;
- life history of sea lice to better understand modes of infection, range of hosts, etc.;
- ways of managing lice levels on salmon farms at as low a level as possible, particularly prior to the spring period for migration;
- parasite-induced host mortality at the population level;
- lethal and sub-lethal effects on marine invertebrates of chemicals used to treat sea lice;
- prevalence and distribution of lice during sea lice outbreaks in particular areas;
- the behaviour of salmon smolts and returning adults in inshore waters in the vicinity of farms.

At a meeting of experts on sea lice in B.C. in 2002, research priorities were identified (Healey 2002). The overall objectives were to determine: if native species experience increased rates of parasite infection due to salmon aquaculture, if any increases in infection pose a significant risk to survival or commercial productivity of native species, and how any effects of increased parasitism could be mitigated.

Studies to evaluate any effect of sea lice on salmon farms on wild salmon will be difficult to conduct. It is important to note that any impact of salmon farms must be considered an incremental source of mortality. Typically, estimates of natural mortality on salmon at sea are greater than 85% to 95% (i.e., 85 to 95 of every 100 juvenile salmon that go to sea die by natural causes – some possibly due to the natural occurrence of sea lice in that environment). These values of natural mortality were determined before concerns about sea lice and salmon farms were considered. Studies of the sea lice issue then must determine the incremental impact of sea lice and salmon farms relative to a large and variable natural mortality.

3.2.5 Assessing the risks to wild salmon posed by sea lice

Causality in lice transfer still has not been proven to the highest scientific standards.

There is no direct proof that there is transfer of lice from farmed fish to wild fish. To prove causality according to scientific standards such as Hill's criteria, there has to be confirmation of a source of lice from farms, and evidence that wild salmon and the parasite from the farms come into contact. As well, the effect (numbers of lice transmitted) must be significantly above that from wild sources. This is difficult to determine on a temporal (before/after) basis due to lack of information on natural levels of lice previous to salmon farming. Nevertheless, in the case of sea lice transfer, at least the following five criteria out of Hill's nine criteria appear to be met, if experience from various jurisdictions is taken into account:

- The association between the exposure and the disease has been observed by different persons, in different places, circumstances and times (Consistency of Association).
- The exposure closely precedes the disease (Temporality).
- An increase in exposure produces an increased frequency or severity of the disease (Biological Gradient).
- The hypothesized causal relationship is biologically plausible (Plausibility).
- The causal relationship is consistent with the known natural history and biology of the disease (Coherence).

And research may soon, if it does not already, allow a sixth criterion to be met – Experimental Evidence (evidence from research in other populations that shows the same relationship).

European studies are beginning to confirm a connection between salmon farming and sea lice on wild salmon.

Mainly as a result of studies in Norway and Scotland, the scientific arguments for links between sea lice on farmed salmon and mortality of wild smolts are building strength. The Scottish Executive recently concluded that although there is as yet no absolute proof of a causal link between sea lice on wild salmon and salmon farming, "owing to the increasing body of supporting (although as yet inconclusive) evidence, the burden of opinion has recently begun to swing in favour of accepting the likelihood that lice from farms constitute a direct threat to wild salmonids." (2002, p.25) This report goes on to say: "If protecting wild salmonid populations is agreed to be important then it is likely that lice transfer from farmed salmon will limit the scale of the industry, particularly in areas with important populations of wild fish." (p.40)

The European Commission (2002) has recently concluded "The reduction of wild salmonid abundance is also linked to other factors but there is more and more scientific evidence establishing a direct link between the number of lice-infested wild fish and the presence of cages in the same estuary."

We can learn from experience in other regions, with caution.

Given the consensus that appears to be building in Europe around the connection between salmon farms and sea lice, the important question arises as to how transferable European experience is to the B.C. context.

Compared to other jurisdictions, sea lice have not yet posed as significant a problem for farmed-wild salmon interactions in British Columbia. Why have lice not reached the magnitude of a problem on the B.C. coast that they have in Europe? Some of the basic factors relevant to the sea lice issue are similar in Europe and B.C. For example, most European and B.C. farms are located in bodies of water with a similar geography. They are somewhat contained – a Scottish loch, Norwegian fjords, bays and inlets in B.C. Tides and temperature may vary but it is moot as to whether such differences would be significant regarding sea lice. Possible sources of differences in sea lice dynamics in different regions include:

- Number of host species for the parasite on farms are higher relative to the number of wild hosts in Europe. "Based on rough estimates of pre-fishing abundance there was at least 120 times more farmed than wild salmon in Norwegian waters in 2000." (Forseth 2001, p.28) Greater numbers of farms mean more potential reservoirs of lice.
- High levels of precipitation and fresh water runoff on the B.C. coast makes the water less saline than in Europe (27-29 parts per thousand) and thus less hospitable to lice, which prefer 30-32 parts per thousand. Further north in B.C. and in Norway the water is more saline (Grydeland, pers. comm. 2002).
- Farm and wild host species have more commonality in Europe than in B.C. In both cases, the species in association are salmonids. However, in Europe, the farmed species and the wild species are both Atlantic salmon, while in B.C., the farmed species are usually Atlantic while the wild species are Pacific. Pacific salmon seem more resistant to parasites, but their smolts are smaller than Atlantic salmon smolts in Europe and thus may be more susceptible in the early stages.

Circumstantial evidence that lice spread from farms to wild salmon is convincing.

Scientific studies in Europe are increasingly assertive about the likelihood of the contribution of salmon farming to sea lice in wild salmon (McVicar 1997, Scottish Executive 2002, Gargan 2000, Bjorn et al. 2001, Bjorn and Finstad 2002, Tully et al. 1999, Tully and Whelan 1993, Butler et al. 2001, Ross 2002).

Differences between the situation in B.C. and Europe are not sufficient to provide assurance that the more extreme problems of sea lice transfer acknowledged to exist there will not be encountered in B.C.

A study in B.C., by Raincoast Research in the Broughton Archipelago, has also shown significantly higher infestations of wild salmon in areas close to farms as compared to areas less exposed to farms. While there are other possible explanations for high levels of lice on wild salmon, some credence must be given to the independent documentation of increased sea lice infestation on pink smolts migrating past farms.

Our knowledge of the biology of the salmon louse supports the feasibility of lice transfer from farmed to wild fish, and from wild to farmed.

Thus, the European research, preliminary studies in B.C., and knowledge of sea lice-salmon dynamics presents a body of compelling evidence that sea lice can be transferred between farmed and wild salmon. The remaining questions are mainly ones of degree. To what extent does infection occur? How serious are the consequences of that infection? How much can preventive measures reduce the extent of the problem? Perspectives on this latter question are addressed below.

Improvements in fish health management at the farms will reduce the potential for farms to transfer lice to wild salmon but not eliminate it.

Actions that result in lower lice loads on salmon farms will also help wild salmon by lowering the number of potential pathogens available to infect wild salmon under appropriate conditions. However, Forseth (2001) has cautioned that even though synchronized and intensified delousing have reduced the number of sea lice on each farmed salmon in Norway, the continuous growth in the number of farmed salmon rapidly outweighs the measures taken.

3.3 Bacteria

3.3.1 Bacteria and salmon

Bacterial diseases of concern to salmon farming include bacterial kidney disease, typical vibriosis, coldwater vibriosis, winter ulcers, furunculosis, yersiniosis, myxobacteriosis, and salmonid rickettsial septicemia (Evelyn et al. 1998). Bacterial diseases cause serious and recurring losses in pen-reared salmon. All salmon species reared in net pens are susceptible to bacterial diseases, but some diseases are more problematic in certain species and regions than in others (Evelyn et al. 1998).

Bacterial Kidney Disease (BKD)

The causative agent of BKD, *Renibacterium salmoninarum*, is ubiquitous in wild Pacific salmon. BKD is probably the most significant cause of mortality in pen-reared chinook and coho salmon (possibly recently overtaken by IHN; see Section 3.4.2). Atlantics are susceptible, but to a lesser degree. Sockeye, pink and chum are extremely susceptible.

The BKD bacterium is transmitted vertically through the egg, as well as horizontally (in freshwater and seawater). The disease can occur in fresh water, and fish can carry the infection to seawater, serving as a potential source of infection (Evelyn et al. 1998). Outbreaks can occur throughout the year and at all stages of the life cycle.

BKD induces severe, chronic inflammation in the kidney, other organs, and to a lesser extent the muscle. The disease develops slowly from the time of infection into a chronic condition and can become terminal (Whoriskey 2000b).

Vibriosis

In salmonids, typical vibriosis is caused by *Vibrio anguillarum*. It is a pathogen that affects many marine fish and invertebrates worldwide, including farmed salmon. It is more acute than BKD. The bacterium occurs commonly in the seawater and marine sediments. Although the bacterium may cause disease in salmon other than farmed salmon, serious losses were first noted in farmed salmon (Evelyn et. al 1998).

Vibriosis results in systemic infections and deep red ulcers on the skin and can cause high acute mortality in unvaccinated smolts.

Cold-water vibriosis disease is caused by *Vibrio salmonicida*. The most severe outbreaks typically occur at low temperatures during the winter months. Cold-water vibriosis disease is not considered as a very pathogenic bacterium and a massive exposure is required to infect the fish (Evelyn et. al 1998). To-date, *V. salmonicida* has only been reported in the Atlantic Ocean and is not known to occur in the Pacific.

Furunculosis

The causative bacterium of furunculosis is *Aeromonas salmonicida*. Furunculosis is an extremely contagious bacterial disease that occurs naturally in both oceans, and is known in hatchery and wild salmon. It became a serious disease of salmonids reared in seawater, particularly in farmed Atlantic salmon. It is no longer perceived as a major problem for salmon farming due to the availability of a vaccine (Hiney and Olivier 1999).

Using antibiotic fingerprinting, industry research in Scotland found that *A. salmonicida* could move up to 19 kilometres between unrelated farms. And in 1993, a B.C. farm was infected with an easily identifiable strain derived from infected smolts at another company's farm 10 km away (Needham 1995). Survival of the pathogen outside of the host in fresh water, freshwater sediments, and seawater can be prolonged: the bacterium can remain infective in organic waste in seawater for up to 56 days (Evelyn et. al 1998, Needham 1995).

As in the case of BKD, furunculosis-infected fish can carry the infection into seawater, and horizontal transmission can occur in net pens (Evelyn et. al 1998). Furunculosis is not vertically transmitted. Infected fish are the chief reservoirs of infection. Fish that survive an outbreak can carry the pathogen and transfer it to other fish (Heggberget et al. 1993).

3.3.2 Points of view on bacteria issues

Will bacteria become resistant to antibiotics?

Point of view: Antibiotic resistance can occur as a result of antibiotic treatments.

The *A. salmonicida* pathogen often becomes resistant to antibiotics routinely used for treating the disease. That is, the antibiotics can "select for" strains of the causative bacterium with antibiotic resistance on salmon farms by killing the bacteria that are vulnerable to the antibiotic while allowing other, resistant bacteria to multiply. Outbreaks may thus recur shortly after treatment has terminated. In addition, mixed infections can occur, in which some fish are infected with antibiotic sensitive strains of *A. salmonicida*, while others from the same population are infected with resistant bacteria (Evelyn et. al 1998).

The process that leads to antibiotic resistance is as follows. Any natural population has within it chance mutants of the bacteria that are resistant to certain antibiotics. There are different resistance patterns even among bacteria within an individual fish. Repeated use of the same antibiotic kills the non-resistant members of the bacteria population. The resistant bacteria then have the opportunity to multiply, and antibiotic-resistant bacterial populations can build to higher levels than non-resistant bacteria. This is called selection pressure. When the antibiotic is not used for a period of time, the resistance recedes as the bacterial population reproduces, or other bacteria enter the population from areas not treated (e.g., from outside of a farm).

Long term use of antibiotics poses concerns, however, as it provides more opportunity for normally scarce, resistant bacteria to multiply. Although antibiotic resistance is not permanent, it may restrict the success of disease control efforts, especially if the number of antibiotics for use is limited (Brackett and Karreman 1998).

See Section 3.5.2 for a discussion of the risks of new strains of bacteria developing.

Point of view: Antibiotic resistance, as caused by the use of antibiotics on farms, is of limited relevance to wild fish.

Resistance caused by the use of antibiotics is not permanent if the use of the antibiotic is not continuous. The normal population make-up will return when the drug is no longer around to force selection of resistant bacteria (Brackett 2000). At that point, e.g., six months later, an antibiotic that had become ineffective can be used again. The judicious use of antibiotics, involving careful matching of the antibiotic to the target organism, and the timing and duration of its application, minimizes the potential for the development of antibiotic-resistant bacteria. When more than one antibiotic is available and effective in treating a disease, rotation of the products for subsequent outbreaks on a farm also helps reduce problems of resistant populations of bacteria (Brackett and Karreman 1998).

The bacteria that are selected for through antibiotic resistance are not necessarily the hardiest representatives of the population and their numbers only become high due to the artificial selection process. These *selected* bacteria are not newly created or mutated bacteria and they are not necessarily stronger or more virulent. For example, testing by DFO determined that the resistant furunculosis strain that developed as referred to by Morton (Raincoast Research 1995) was relatively less pathogenic (Morrison 2002b).

Because the antibacterial treatments, which are administered in food, are not being applied to wild fish, there is no encouragement for those resistant bacteria to become a more prevalent population in the wild fish. The farm-specific selective pressures which allow their development at farm sites do not exist in the wild, so the natural variation of bacteria presents the same risk to the wild fish that it did before the antibiotics were used (Morrison 2002b, McVicar 1998b). The potential for risks to wild stocks from changes in bacterial disease characteristics in farms is therefore limited (McVicar 1998b).

Were wild (and hatchery) fish impacted by furunculosis from farms in the early 1990s?

Point of view: High mortalities of wild chinook from furunculosis in Kingcome Inlet coincided with the presence of antibiotic-resistant strains.

One alleged connection between salmon farms and the spread of a bacterial disease to wild salmon in B.C. was documented in research by Raincoast Research (1995). The study examined anecdotal evidence around introductions of Atlantic smolts infected by *A. salmonicida* to the Broughton Archipelago. The authors conjectured a number of negative events resulting from infection of smolts at a hatchery supplying B.C. salmon farms, namely: infection of salmon farms in the Broughton Archipelago by these smolts; spread of the furunculosis infection between farms by boats; transmission of the pathogen to wild salmon through water and escaped salmon; and declines in local chinook stocks as a result (particularly as indicated by salmon returning to an enhancement hatchery and as reported by fishermen and sport fishing lodges). Morton (2001b) identifies antibiotic resistance as a connecting factor. She observes that chinook stocks collapsed in Kingcome Inlet the year after their run had passed farms that had been infected with a strain of furunculosis resistant to the usual antibiotics. As well, 55% of the broodstock in a nearby enhancement hatchery (Scott Cove Hatchery on Gilford Island) died from furunculosis which also exhibited antibiotic resistance (Morton 1995).

Point of view: Other factors could explain the furunculosis outbreak in the wild salmon.

McVicar stated that, while antibiotic-resistant strains of bacteria did develop on farms in the late 1980s due to the extensive use of antibiotics to combat furunculosis and vibriosis, there is no direct evidence that these strains spread to wild stocks (McVicar 1998b). In this particular case, the chinook salmon in the hatchery had been treated with antibiotics, perhaps explaining the antibiotic resistance in *A. salmonicida* isolated from them. Also, the strain (a genetic variant of the bacterium) of antibiotic resistant bacterium isolated from the farmed fish in the area differed from the hatchery strain.

If an antibiotic-resistant strain of *A. salmonicida* was present in the farms and/or hatchery, it is possible for transfer of that bacterium to wild fish. However, the presence of the bacterium does not mean that disease must occur; there would have to be some causative agent for the infection to develop. Furunculosis outbreaks in the wild may be connected with stress from high densities, high temperatures, low flows or aggressive interactions at spawning. Sea lice could transfer the disease to migrating salmon, and/or adults may pass the bacterium horizontally to juvenile salmon. DFO representatives stated that low rainfall and high stream temperatures had likely contributed to the collapse of chinook populations in the area described above. Also recall that antibiotic-resistant bacteria are not necessarily more virulent, so the presence of such bacteria is not an adequate explanation for the expression of disease.

For the Salmon Aquaculture Review, Stephen and Iwama (1997) considered the possibility of furunculosis transfer from farms to wild stocks. They acknowledged that the large numbers of *A. salmonicida* cells released into the water during furunculosis outbreaks increase the possibility that fish that come into contact with infected farms might become infected. They pointed out that scientific evidence from several studies indicates that survival of the pathogen outside of the fish host is short term in marine environments, particularly when they contain other (competing) organisms. This assertion is somewhat inconsistent with information from Needham (1995) and Evelyn et al. (1998), who describe an ability in the *A. salmonicida* bacteria to survive outside of the host in seawater. They see this as a means by which fish at one farm can be infected by fish at another farm, even when the sites involved are separated. However, Evelyn (pers. comm. 2002) noted that results cited in Evelyn et al. (1998) were determined in the absence of competing organisms and that survival could be less in the natural environments.

3.3.3 What can be done about bacteria in relation to netcage salmon farming?

Preventing/treating bacterial diseases with vaccines and antibiotics

Vaccines are generally more feasible for bacteria than viruses due, in part, to the nature of the antigens that trigger the immune response in fish. Effective vaccines are available for vibriosis, furunculosis, and yersiniosis (Evelyn et al. 1998). Every smolt is vaccinated prior to being transported to the ocean net pens for two vibrios and furunculosis in Atlantics salmon, and two vibrios and BKD in chinook salmon. Furunculosis and vibriosis are considered to be well controlled, throughout grow-out, by vaccination of smolts. Nevertheless, outbreaks of various bacteria that are not vaccinated for do occur, to the extent that bacterial diseases are common in pen-reared salmon.

Antibiotic treatments are used when the disease is observed clinically, that is, late in the development of the disease. Use of antibiotics has been dropping due to improved preventive measures, faster detection and earlier treatment (Brackett and Karreman 1998). A U.S. report states that reductions in use of antibacterial drugs in B.C. have been similar to Norway, where the reduction was ten-fold between 1987 and 1993 (Nash 2001). Only four antibiotics are licenced for use in B.C.

One of the concerns associated with the use of antibiotics is that residual antibiotics will be absorbed by other marine species and possibly be consumed by humans or will continue to select for antibiotic-resistant strains of bacteria. Aspects of this issue are discussed in Section 5.2.1 of this report.

Preventing/treating Bacterial Kidney Disease

Since the BKD pathogen can be vertically transmitted, broodstock are carefully screened and eggs are tracked. If the female parent is found to be infected, all her eggs are discarded. A BKD vaccine, Renogen (licensed in Canada in 2000), has recently entered use (Daly et al. 2001).

Managing stress is important in avoiding BKD outbreaks, for example by limiting stocking densities and ensuring good water quality. The disease is difficult to treat with antibiotics (although these are sometimes used).

Preventing/treating Vibriosis

Vibriosis is largely controlled by vaccination. Yet failures of protection in vaccinated Pacific salmon, particularly with chinook, have occurred at a number of fish farms in B.C. The cause of these failures has not been determined, but the most likely explanation is that the fish may have been vaccinated too soon (Evelyn et. al 1998).

Optimization of the environment and reduction of stressors, in particular during the winter months, are important measures to avoid outbreaks of cold-water vibriosis (which is not known in Pacific region, Atlantic only). It is important to isolate diseased fish from healthy fish, and the bacterium will normally respond to treatment by antibiotics (Evelyn et. al 1998).

Preventing/treating Furunculosis

Like vibriosis, furunculosis in farmed fish is kept in check by a vaccine. Other means of prevention include: avoid using smolts with a history of the infection, single year class farms, surface-disinfected eggs, raising fry in clean water and checking for infection before putting the fry out to the pens. However, since high pathogen levels can overwhelm vaccines, and preventive measures can fail, outbreaks do occur.

The contribution of stress to furunculosis and other bacterial outbreaks is reduced through matching stocking densities to the farm site, depending on water flows and the range of temperature extremes (Needham 1995). As well, farmed salmon should not be handled when temperatures are relatively high.

The issue of antibiotic resistance in the treatment of furunculosis is discussed above.

3.3.4 Gaps in our understanding of issues related to bacteria

Bakke and Harris (1998) summarized knowledge on diseases and parasites in wild Atlantic salmon. They found that, while bacterial diseases like furunculosis and BKD pose serious health challenges to both farmed and wild salmonids, knowledge of their cause is incomplete. They also pointed out that for most bacteria (i.e., other than furunculosis and BKD) there appear to be no records of outbreaks of these diseases in wild salmon. This may be because their pathogenicity is so great that infected fish die before they can be sampled (Bakke and Harris 1998).

Wiens and Kaattari (1999) recommend that, to improve the control of BKD, research is required to understand *R. salmoninarum* virulence factors, infection processes and the salmonid immune response to the bacteria. Actis et al. (1999) call for investigations into the virulence mechanisms of the various vibrios.

3.3.5 Assessing the risks to wild salmon posed by bacteria

Wild salmon are capable of resisting bacteria found in B.C.'s coastal waters, yet they are still somewhat vulnerable to infection.

The causative bacterium for bacterial kidney disease is so prevalent in wild fish that it is commonly felt that the risk of their being infected by farm sources is very low. Kent (2002) reports on a study that found similar levels of BKD in wild and farmed chinook salmon. Bakke and Harris (1998) state that it is likely that there are no transmission cycles for bacteria like vibriosis between farmed and wild fish. On the other hand, Hastein and Lindstad (1991) commented that a heavy infestation of BKD in farmed fish could pose considerable infectious pressure on wild fish populations.

Concern over the potential for transfer of furunculosis from farmed to wild salmon is warranted despite the lack of direct evidence, but the effective use of vaccines substantially reduces the risk.

Much attention has been paid to the potential for spread of *A. salmonicida* (furunculosis) via salmon farming. While furunculosis occurs naturally in the Pacific region, outbreaks can cause severe mortalities and rarely is the pathogen found in wild Pacific salmon at sea. Mature wild fish may be affected during outbreaks, and the damage can be catastrophic for populations if a significant number of broodstock die before spawning (Johnsen and Jensen 1994). As mentioned above, Stephen and Iwama (1997) acknowledged that the large numbers of *A. salmonicida* cells released into the water during furunculosis outbreaks increase the possibility that wild fish that come into contact with infected farms might become infected. Bakke and Harris identify several ecological factors that "provoke concern for the potential impact of furunculosis spreading from farms to wild salmonids": sea lice could transfer the disease to migrating salmon; adults migrating upstream could pass furunculosis on to immature salmon in their nursery rivers; and escaped farmed salmon could infect wild salmon populations (1998, p.252). Evelyn et al. (1998) suggest that transfer of the furunculosis pathogen between farmed and wild stocks is certainly possible. However, a recent review concludes that, although the possibility of furunculosis transfer is discussed in many scientific publications, none of these published reports provide direct evidence of this transfer (EVS 2000).

A remaining issue, related to the potential for furunculosis treatments at farms to lead to new strains of the bacterium, is discussed in Section 3.5.2.

The main source of reassurance concerning the risk of furunculosis transfer from farmed to wild stocks is that vaccines and antibiotics can now effectively control the disease. "Finally, with the increased use of anti-furunculosis vaccines on salmon farms in B.C., the risk of furunculosis outbreaks occurring has been drastically reduced. The risk to wild fish in B.C. has thus been correspondingly reduced." (Stephen and Iwama 1997, p.4)

3.4 Viruses

3.4.1 Viruses and salmon

Viral diseases of concern in salmon farming include infectious hematopoietic necrosis (IHN), salmon pancreas disease, infectious pancreatic necrosis (IPN), infectious salmon anaemia (ISA), salmonid herpesvirus 2 and erythrocytic inclusion body syndrome (Traxler et al. 1998).

Viral diseases of fish have historically been of great concern to fish health managers because they can cause high mortality (Traxler et al. 1998). A common effect of viruses is disruptions to the circulatory system of the fish, causing haemorrhaging, anaemia and bloody patches on the skin and organs. Documented transmission mechanisms for viral infections include fish carriers, movement through the water, and human activities.

Currently, IHN is of most concern in British Columbia. In Europe, diseases currently posing challenges to salmon farming include IPN and salmon pancreas disease (Staniford 2002). ISA is also presenting problems in several regions of the world, including Canada's east coast, but is not known in B.C. IHN and ISA are the focus of analysis in this section.

Infectious Hematopoietic Necrosis (IHN)

IHN is one of the most costly viral diseases of cultured salmon in North America. It has been recently identified as the cause of significant mortalities in farmed and enhanced salmon in the Pacific Northwest. The disease process is very aggressive and acute, particularly in smaller juvenile salmon (Saksida 2002).

The causative agent of IHN is a virus with the same name as the disease: the infectious hematopoietic necrosis virus (IHNV). There are three strains or forms of the virus (i.e., genetically identifiable isolates of IHNV) that can be grouped according to the regions in which they presently occur: northwest coast (Oregon to Alaska), California, and Idaho and Columbia River. There are increasing areas of overlap between strains as the recently identified Idaho form spreads within the Columbia River basin.

IHN has been found in B.C. in wild salmon and Atlantic salmon as well as a variety of wild, non-salmonid marine fish (MAFF 2002b). The virus is cyclical and is particularly common in the coastal sockeye populations, in which it has caused high mortality in early life stages. Outbreaks of the disease have been reported primarily in juvenile sockeye and occasionally in juvenile chum salmon in fresh water. The majority of documented outbreaks in wild Pacific salmonids occur in fresh water as spawning salmon develop and release high levels of the virus (Bootland and Leong 1999).

Susceptibility to IHN disease varies between the species and with the strain of the virus, although virtually all species of Pacific salmon, as well as Atlantic salmon, are susceptible. While wild salmon can carry the virus and be sub-clinically infected, the disease has not been frequently detected in salmon at sea, since they have developed a resistance over the centuries. Among the wild salmon, coho and pink are the least susceptible to the virus. Chinook and chum are also resistant. Sockeye fry migrating from spawning channels have been known to suffer high mortality due to IHNV (Traxler et al. 1998, p.36), so the disease is often referred to as "sockeye flu." Atlantic salmon are highly susceptible to IHN, having less natural immunity. As with many other diseases, smaller, younger fish are more susceptible, and factors such as density and environmental stressors contribute. Young fish show signs of IHN and moralities within five to ten days of exposure (Bootland and Leong 1999).

Adult coho have been reported as carriers of the virus when being held at the same salmon farm site as chinook salmon adults with IHN (Traxler et al. 1998). About 3% of all chinook stock in wild populations carry IHN (Chettleburgh 2002). Species other than salmonids, such as herring or shiner perch, may also be carriers.

Transmission occurs as the virus is carried downstream (by water) from spawning areas where infected sockeye die and shed the virus into the rivers. Diseased fish entering the sea also release the virus (Sverre 2002). Likewise, IHN infected fish held in net cages shed the pathogen into the environment (Werring 2002). Horizontal transmission readily occurs, as the virus can retain infectivity in water at 10°C for up to seven weeks (Hastein and Lindstad 1991), or even for several months, according to Bootland and Leong (1999). Longer and shorter survival times depend on environmental conditions. The minimal dose and exposure time required for transmission are not known (Saksida 2002). Seawater reservoirs for the virus are likely supported by the presence of the virus in wild sockeye salmon, according to Traxler et al. (1998), while Bootland and Leong (1999) state that no naturally occurring marine reservoirs for the disease have been confirmed.

Infectious Salmon Anaemia (ISA)

ISA is caused by a virus called "orthomyxovirus" that is genetically different in Chile, Europe and New Brunswick. The virus is shed through skin mucus, urine and feces from infected, healthy-appearing carriers before they develop clinical signs of the disease. The disease spreads like influenza – through contact with infected fish or contaminated water – and is ultimately fatal (Archibald 2000, Whoriskey 2000a). It is possible, however, for fish to carry the virus without showing signs of the disease until they are stressed by other factors. Like a flu virus, ISA can mutate and evolve.

Natural outbreaks have occurred in Atlantic salmon only, but other salmonids may harbour the virus (Traxler et al. 1998). Most outbreaks occur during rapid temperature increases in the spring, but may also occur in late autumn.

It is unknown whether ISA is endemic and found in wild fish which then transmitted it to farmed fish, or the reverse (Standing Senate Committee on Fisheries 2001b). A U.S. Department of Agriculture technical note states that ISA can be transmitted and spread between and through wild and farmed fish populations and geographic areas by direct contact between infected and uninfected fish (APHIS 2002). This note also explains that the virus can be transmitted through movement of infected fish, via farm equipment, and on sea lice. Epidemiological studies in Norway and Canada have shown that other factors that increase the spread of the disease include effluent from plants that process the diseased fish, close proximity of farms, higher stocking densities and fewer sea lice treatments (Whoriskey 2000a).

The global spread of ISA

Outbreaks of ISA in natural populations have only been recorded in Norway (Dannevig and Thorud 1999). ISA was first detected on a smolt farm in Norway in 1984. It then spread to most fish farming areas along Norway's coast and was economically significant for the Norwegian fish farming industry (Dannevig and Thorud 1999). (More recently, a government report has stated that the incidence of ISA is stable and relatively low in Norwegian aquaculture facilities (Norwegian Directorates 2000)). The disease was later detected on farms in New Brunswick, and then in wild salmon in Scotland (Archibald, 2000). In 1998-99 in Scotland ISA led to the destruction of 4 million salmon, the setting up of a 'National Crisis Centre' and a quarter of the industry was placed in quarantine. The ISA virus has since been found in wild salmon, trout and eels in Scotland. In February 2000 the European Parliament's Fisheries Committee reported that: "clearly the containment of ISA is of concern not only to Scotland, but to the Community as a whole" (in Staniford 2002). ISA was found in Chile in 1999, on the Faroe Islands in 2000, in Maine, U.S. in 2001, and it was reported in an escapee rainbow trout in Ireland in August 2002 (APHIS 2002 and Staniford 2002). In March, 2001, it was found in U.S. waters, infecting salmon farms in Maine (Barcott 2001). In 2001 Maine producers lost 2.5 million salmon due to an outbreak of ISA, and Cobscook Bay had to be cleaned of salmon and then restocked (Campbell 2002).

ISA in New Brunswick

The east coast Canadian epizootic began in August 1996. The New Brunswick Fisheries and Aquaculture Department ordered the slaughter of more than 1.2 million salmon in a1998 in an effort to control one ISA outbreak (Barcott 2001). ISA was first reported in wild Atlantic salmon in New Brunswick in 1999 (Whoriskey 1999). As of July 31st 2002, 15 sites had tested positive for ISA in the Bay of Fundy, leading to the destruction of another 980,000 fish. The General Manager of the New Brunswick Salmon Growers Association stated to the press in August 2002, "We are testing everywhere. The more you test, the more you find." (Campbell 2002) Compensation and insurance from government and/or industry have been matters of debate, with some compensation having been paid to farmers required to cull their stocks. Questions of compensation are said to have delayed the culling of infected fish by farmers who chose to keep the fish for harvest when they could not obtain compensation (Friends of Clayoquot Sound 1998).

3.4.2 Points of view on virus issues

This discussion focuses on the two viruses of most pressing concern in Canadian salmon farming. IHN occurs naturally in B.C. but outbreaks at farms over the past two years have been of particular concern. ISA has not been experienced on this coast. Its spread between other regions of the world has led to fears that it could be introduced to B.C.

What was behind the recent outbreaks of IHN in salmon farms on the B.C. coast?

The first confirmed report of IHN in salmon farms in British Columbia was in 1992, and outbreaks occurred in 1995, 1996,1997 and 2001. The outbreaks historically have been mainly in the Campbell River/Quadra Island area and less around northern and western Vancouver Island (Traxler et al. 1998, MAFF 2002b).

Between August 2001 and May 2002, 19 Atlantic salmon farms became infected with IHN virus (Saksida 2002). The farms were widely dispersed, from Klemtu on the Central Coast to the Broughton Archipelago and Clayoquot Sound. Testing to determine the nature of the IHN isolates suggested that there were two independent new introductions of IHNV to the farms with both sources being endemic to B.C. (Saksida 2002). Industry representatives stated that the smolts delivered to the farm sites did not have IHN (*The Daily News*, March 25, 2002), and a review of freshwater screening also suggested that the IHNV could not have come from freshwater sources (Morrison 2002a). A report by a veterinarian commissioned by the MAFF and the B.C. Salmon Farmers Association (Saksida 2002) stated "We do not know what factors led to the 1992 and the 2001 IHN disease events in the farmed Atlantic salmon." Saksida (2002) reviewed the potential sources of infection and transmission as the virus spread between farms in the 2001 epizootic, based on interviews with the salmon farmers and a review of the literature. Her results can be summarized as follows:

- Sockeye, chinook, and coho salmon assembling in the area on their regular migration back to the rivers to spawn may have spread the disease.
- Results point to waterborne exposure as a likely means of transmission from farm to farm based on the pattern of water movement in the affected area.
- Moving of Atlantic salmon to farms in the area past sites with unconfirmed IHN, and movement of infected but undiagnosed fish past "clean" sites could have contributed to the transmission of the disease, as could one instance of introduction of chinook to a site.
- Moving boats and equipment between sites could have transmitted IHNV between farms.
- In two cases no safeguards for harvesting infected fish were in place prior to harvesting because the infection had not yet been confirmed. As well, the effectiveness of the methods for disinfecting the high volumes of harvest blood water and process water was questionable.

Other risk factors that Saksida (2002) suggests may have contributed to the severity of the outbreak include the lag time between suspicion and confirmation of IHN, which ranged from five to twenty-one days. This means that biosecurity barriers likely were not set up quickly enough. In addition, several of the farm populations may have been undergoing some elevated levels of stress prior to the onset of IHN, and it appears that the mortalities were highest in pens that were stressed. One of the stresses reported by industry representatives was the higher stocking densities which had been reached during the moratorium (Grydeland, pers. comm. 2002). In addition to the inability to expand to new sites, low prices for salmon in 2001 and 2002 may have led to higher production volumes in net pens.

Is ISA likely to spread to B.C. through salmon farming?

Because so little is known about the ISA virus, there is no evidence that it could, and no evidence that it could not, spread to B.C. Some feel that it is only a matter of time before ISA is brought here, since "ISA is now found in almost every country from which Canada imports Atlantic salmon eggs" (MacBride 2001, p.4). Others believe that precautionary measures around the import of eggs will prevent the accidental importation of the virus (see Section 3.5.1 on the risk of importation of exotic pathogens). Moreover, B.C. salmon farming companies use eggs from their own broodstock rather than imported eggs.

3.4.3 What can be done about viruses in relation to netcage salmon farming?

Preventing infection by viruses

Prevention is critical to minimizing the health impacts of viruses, because there are no treatments for viral infections. In contrast to bacterial diseases, there is only one commercially-available vaccine for viruses of salmon (i.e., infectious pancreatic necrosis virus), and no drugs are available for their control (Traxler et al. 1998). Antibiotics are not effective against viral diseases.

In freshwater hatcheries IHN is controlled by avoiding the infection. This is achieved by avoiding brood fish from areas where IHN has been diagnosed, using eggs from IHN virus-free females (determined by screening), disinfecting eggs, disinfecting facilities and equipment during and after egg take, rearing eggs and fry in IHN virus-free water and screening for viruses prior to moving fish between areas (Saksida 2002 and Traxler et al. 1998).

At the ocean sites, basic good husbandry practices to minimize stress (see Section 3.5.3) and biosecurity measures (see below) are the main preventive actions. Lower stocking densities are also key to minimizing viral outbreaks.

Technical experts involved in the salmon farming industry in B.C. have reported that there is increasing interest among salmon farming companies in diversification to chinook, in reaction to the IHN risk posed to Atlantic salmon (Drews 2002). However, chinook are more susceptible to BKD, which can cause significant losses throughout the production cycle. For Atlantic salmon, disease problems tend to be concentrated more at the smolt stage, lowering the financial costs of losses due to disease (Chettleburgh 2002).

Will vaccines eventually help in controlling viruses?

To date, commercially available vaccines have primarily been developed to deal with bacterial diseases. Viral vaccines have been slower to develop and experimental vaccines to protect against IHN and ISA have not yet been proven to be effective in salmon net-pen situations. An autogenous (i.e., produced within the fish themselves) vaccine used on a B.C. farm that experienced an outbreak of IHN did not prove to be effective in protecting the fish. Nevertheless, experience with other vaccines and past work on IHN vaccines suggests that an IHN vaccine may be feasible (Casey 2002). The critical viral antigens needed to induce immunity have been defined and cloned for IHN and several other virus diseases of fish, including infectious pancreatic necrosis (IPN) and viral hemorrhagic septicemia (VHS). It has also proven feasible to use DNA vaccination as an approach to immunize fish (Stevenson 2001, Traxler et al. 1998).

Effective vaccines may exist that are not economically practical to administer at a large scale. Vaccines also have to meet stringent regulatory criteria concerning their effectiveness in a farm situation and their compatibility with a food animal.

Measures taken in response to IHN outbreaks in B.C.

Regardless of preventive efforts, virus outbreaks do occur. The manager of a fish farm in Clayoquot Sound that suffered an IHN outbreak despite following the protocols for prevention said, "These are young fish, and their immune systems are naïve. … The site had been properly fallowed for six months, the nets were disinfected and all the ropes were brand new." (*The Daily News* 2002) Given that there is no treatment for IHN disease (as with most fish viruses), responses to outbreaks generally focus on limiting the consequences and spread of the disease.

A representative of the B.C. Salmon Farmers Association (Odd Grydeland) stated that different farm companies and sites took different kinds of action to counter and end their particular IHN outbreak, depending on the size and age of their stock and the extent of the problem once it was noticed. As an example, one particular site was totally emptied of all 1.6 million smolts. Others have dealt with the situation by harvesting some fish and isolating others. In some instances efforts were made to take the fish to harvest size (Dodd 2002).

Saksida's recent report describes the responses to the epizootic (outbreak) of IHN in B.C. salmon farms. Of the 19 sites infected with the IHN virus in the August 2001 to May 2002 outbreak, some were harvested out (when the sites contained harvest-sized fish), or culled (in the case of sites with smolts), within a few weeks after detection of the virus. Others were left for months, with at least one site still having fish on site as of September 2002 (Saksida 2002). Harvesting at sites with outbreaks was conducted according to Departmental (DFO) protocols. Isolation protocols established at all sites included ceasing the movement of equipment and increasing the rate of mortality removal by frequent diving and other systems.

The following section discusses isolation and biosecurity measures implemented in response to virus outbreaks, including IHN in B.C.

Isolation and biosecurity measures for viruses

Quarantine is difficult if not impossible in the marine environment, but biosecurity measures are taken to prevent the spread of disease outbreaks, including "facility isolation." Research has found that boats could carry the ISA virus below the water line for up to three days after exposure (Campbell 2002).

In the case of an outbreak of the IHN virus, salmon farming companies in B.C. are required to use isolation measures that include:

- enforcing strict disinfection procedures;
- limiting the movement of all personnel, equipment and boats;
- using separate dive teams to survey sites at each farm;
- special procedures for removal and disposal of dead fish;

- special precautions for harvesting to prevent spread of the disease (MAFF 2002b).

Other possible isolation measures include halting the movement of fish from the affected site to any other non-infected sites; ceasing access by non-essential staff or visitors; and designating boats and equipment used at an affected site for use at that site only.

In New Brunswick, safeguards to keep ISA at bay have included eradication, off-site blood disposal, and a ban on transfer of fish between net pens. In August 2002, the Maine Department of Marine Resources imposed emergency biosecurity measures to prevent the spread of the disease to the U.S. side of the Bay of Fundy. Aquaculture vessels, service equipment and net pens require approval from the Department before entering Cobscook Bay, and vessels must be disinfected below the water line (Campbell 2002). In Norway measures that have appeared to decrease the rate of new outbreaks include mandatory health control in smolt farms, disinfection of sea water used in freshwater farms, disinfection of processing water from slaughtering facilities, and isolation of infected sites and slaughtering of infected stocks followed by fallowing (Traxler et al. 1998).

In B.C. the government recommends that after an IHN outbreak sites should remain fallow for a minimum of three months prior to re-stocking fish to that site (Kieser 2002).

Zoning to limit the spread of ISA is also being employed in all jurisdictions, with severe restrictions being imposed on fish farming in areas where ISA is present. In the U.S., the Department of Agriculture has established ISA-virus-free farm site zones to prevent the spread of the virus. After examining the risks of ISA infection in Norway, exclusion zones of 5 km were established around infection sites – farms within the zone had to be depopulated, based on observations that there was a higher rate of infection within that area. Saksida recommends the establishment of management zones in B.C., in which salmon farmers could coordinate responses to an outbreak of IHN, and between which the potential for transfer of the pathogen could be minimized.

To restrict the spread of ISA, eradication of fish at infected farms is done in all jurisdictions (Whoriskey 2000a). Alaskan 'Sockeye Salmon Culture Policy' similarly requires, in the control of IHN, that all affected or potentially affected fish be killed immediately and the facilities disinfected (Werring 2002). To minimize the risks from IHN outbreaks in B.C., Saksida calls for depopulation of the infected site as quickly as possible, in addition to a number of other measures consistent with isolation and biosecurity priorities as described above. Morrison, another fish veterinarian, also believes that infected fish should be taken out of the water to reduce the potential for exposure of wild fish to the virus (2002b).

3.4.4 Gaps in our understanding of issues related to viruses

Very little is known about the ISA virus, including its impacts on wild stocks. Similarly, there is a general lack of knowledge regarding IHNV in wild and farmed fish populations. The veterinary scientist who studied the recent IHN outbreaks in B.C. concluded that this lack of knowledge makes it impossible to formulate practical yet effective risk management practices (Saksida 2002). She identified the following research needs:

- Study of IHN in wild fish species to determine modes of transmission, differences in virulence of IHNV variants, doses and exposure times for infection, presence of carrier species and states of the virus in those species; and
- Continued monitoring of the IHN pathogen in the farm salmon populations, including determination of risk factors, effects of stress on susceptibility, and development of effective detection and mitigation management tools.

In a related presentation, Saksida suggested future studies on the possibility of a marine reservoir for IHN, impact on wild stock, minimum doses to begin infection, age/size susceptibility and virus strain differences and their movement in wild and farmed fish. Others have recommended studies to determine the innate levels of resistance in wild stocks and the levels of the pathogen being released during an outbreak (Morrison 2002b).

3.4.5 Assessing the risks to wild salmon posed by viruses

The potential for farm sources of viral pathogens to increase infection of wild fish is reduced by the natural resistance of Pacific salmon to enzootic viruses.

There is no direct evidence for transfer of viral infections from farm to wild salmon populations (Bakke and Harris 1998). "The potential exists for transfer of infectious diseases such as ISA and infectious pancreatic necrosis from farmed to wild stocks but the real level of risk is not quantifiable given present knowledge." (Scottish Executive 2002, p.26) The potential is in turn affected by such factors as the life stage of the wild salmon and their condition.

Wild salmon are adapted to endemic viruses like IHN, reducing the potential for catastrophe that might be presented by increased exposure to the virus. Furthermore, it is possible that the natural cycle of IHN has brought the virus to a peak in recent years, and the cycle may decay away in coming years (Evelyn, pers. comm. 2002).

Little is known of the epidemiology of disease of marine salmon, beyond the fact that highly pathogenic organisms such as ISA (not so far experienced in B.C.) are unlikely to have a wide distribution in nature because they would kill salmon before they had dispersed. Nevertheless, "The possibility of organisms such as ISA colonizing smolts on migration and then having a significant impact on marine salmon stocks should be treated very seriously." (Bakke and Harris 1998, p.259)

Farm sites can increase the reservoir for viruses such as IHNV, especially if diseased fish are not culled.

During an outbreak of IHN the mortality rate will vary between fish of different ages. For the larger fish the disease is more chronic and less fatal; thus these fish can survive, for up to a period of months, until it is time for their harvest at a marketable size. At the same time, other fish at the site may not even be infected. At a farm with 1.6 million smolts, only a few smolts may be IHN-infected. For these reasons, salmon farmers are often resistant to incurring the costs of slaughtering all the salmon present at the site of an IHN outbreak as a precautionary measure. Regulations do not prevent them from keeping infected fish in the water, and insurance only compensates farm owners for mortalities at the site. A preventive attitude suggests it would be better to take out all the fish at an infected site.

Saksida (2002, p.15) observes that hypothetically, the presence of an IHN-infected population at a salmon farm "could provide a continuous reservoir of virus not only in the site itself but also in the surrounding area (i.e. downstream)." Werring, then a staff scientist at the Sierra Legal Defense Fund, put it more strongly: "Given that viral particles are being shed on a continuous basis during an outbreak and given that the virus can survive in sea water for several weeks, one can assume … [that] a large expanse of the sea surrounding that fish farm will contain an elevated viral load relative to normal background levels. Thus, by allowing IHN infected fish to remain in the water at IHNV infected fish farms, it is likely that the farms in question are creating marine reservoirs for this disease where such reservoirs have previously not existed …" (Werring 2002)

The business case for the National Aquatic Animal Health Program supports the ordering of stock destruction (i.e., obligatory destruction), with caveats. The caveats are that there is associated compensation, that destruction occurs "when appropriate," and that this applies "in exceptional circumstances." (CAIA 2002, p.5) The latter "circumstances" include the consideration of ecological damage.

Other failures in biosecurity can also contribute to the spread of viral disease, as suggested in the analysis of the IHN outbreak in B.C. (Saksida 2002) and by experience with ISA in other countries. Dannevig and Thorud (1999) report that the spread of ISA between fish farms mainly occurs by the purchase of infected smolts, transport of infected adult fish between farms, and release of untreated water into the sea from nearby processing plants. McVicar (1998b) similarly points out that the spread of ISA within Scottish salmon farms has been closely associated with the multiple use of fish farming equipment between different fish farms.

Migrating salmon could be exposed to IHN from farms.

Juveniles migrating out to sea past salmon farms would be the most vulnerable to infection from contact with diseased fish and the most likely to suffer mortality (although they would likely have to be exposed to environmental stressors at the same time to be susceptible to the virus). It is possible that out-migrating wild salmon could carry the virus to other waters, whether or not they succumb to it themselves (Werring 2002). In the case of returning adult salmon, infection would likely pose a lower risk of mortalities than for juveniles.

Bootland and Leong conclude that "although it is unlikely that fish become infected through the ocean water, because of the high dilution factor, this remains a possibility." (1999, p.98) The analysis of the IHN outbreaks in B.C. by Saksida (2002) suggests that this possibility should not be discounted. The processes suspected to be involved in the spread of IHN during these outbreaks show that even if stocks are destroyed, the released virus may have spread through contaminated water or by tidal currents.

3.5 Points of view on over-arching issues in the potential for disease transfer between salmon farms and wild salmon

There are essentially two ways in which salmon farms can increase the potential for disease transfer to wild salmon. The first is by exposing wild Pacific salmon to new diseases. This issue is analysed in sections 3.5.1 and 3.5.2. The second is by amplifying diseases naturally present in B.C. waters, as examined in sections 3.5.3 and 3.5.4. Moving from possibilities to what we know about actual transfers of disease from farmed to wild salmon, Section 3.5.5 reviews the evidence, or lack thereof.

3.5.1 Are exotic diseases likely to be imported to B.C. through salmon farming?

Point of view: No exotic diseases at present are known to have been imported to B.C. as a result of salmon farming.

Exotic pathogens are new to the resident fish in either farm or wild populations, so the fish will lack the immunity that comes from evolving with the pathogen. The fish are thus more likely to become infected and diseased from the pathogen, although it is not possible to predict the impacts of the introduction of specific pathogens. Because exotic pathogens can potentially cause more harm than enzootic ones, the potential for importing pathogens is a concern.

By all accounts, there have been no pathogens or parasites introduced to B.C. as a result of the movement of fish or eggs for salmon farming. This success is largely ascribed to adherence to regulations and policies applying to the import of fish and eggs. Strict quarantine, and multiple, redundant levels of protection and testing apply. The Policy for the Importation of Atlantic Salmon into British Columbia (established in 1985) allows the importation of surface-disinfected eggs only – not live fish, and far fewer risks are associated with the transfer of eggs than with movements of fish (Bakke and Harris 1998). In addition, only fertilized eggs or milt from sources certified under the Federal Fish Health Protection Regulations are allowed. Furthermore, the eggs and resulting fry must be held in a quarantine facility, and the effluent water from the facility must be disinfected and released to the ground. The resulting juvenile fish are then inspected several more times before they are introduced to farms. Concerns have been raised that surface egg disinfection is not effective against pathogens located within eggs. However, very few fish viruses and bacteria are known to be transmitted intra-ovum. "Under this [above-mentioned] policy, 11.4 million Atlantic salmon eggs have been imported into the Pacific Region since 1985 with no introduction of exotic diseases." (Stephen and Iwama

1997) Moreover, in recent years, B.C. salmon farming companies have only used eggs from their own broodstock rather than imported eggs (Krause, pers. comm. 2000).

Reassurance of a low risk of exotic import can be drawn from the apparently low occurrence of exotic disease outbreak in fish culture globally: "The enormous numbers of fish moved internationally annually coupled with the relatively small number of reports of outbreaks of exotic diseases suggests the probability of exotic disease outbreaks is low, but not zero." (Stephen and Iwama 1997) Atlantic salmon have been in pens on the west coast, in Washington State, for years prior to the industry arriving in B.C., and no exotic diseases have been imported to B.C. from that source (MAFF 2002b). Nor has there been any evidence that salmon farming has led to the importation of exotic fish diseases into Washington waters (Pollution Control Hearings Board 1998). Examples of cases where salmon farming apparently has provided a means for the spread of disease are described below.

Point of view: Exotic diseases could be imported by salmon farming practices, as has occurred in other places.

Precautions to prevent import of pathogens are not foolproof. A group of scientists considering the risk of exotic disease importation via imported eggs concluded that this would be very unlikely, but "it would not be accurate to say that the risk is zero." (Gallaugher and Orr 2000, p.55) Stephen and Iwama (1997) reached the same conclusion in their work for the Salmon Aquaculture Review – that policies governing fish importations reduce but do not completely eliminate the risk of pathogen import.

Raincoast Research (1995) and the Georgia Strait Alliance (1997) have suggested that regulations and policies around importation and sterilization procedures have not been consistently adhered to. Even careful precautionary measures include a margin of error; e.g., if surface disinfection removes up to 99.8% of a horizontally transmitted pathogen, the small amount left over can still present a risk for transmitting the disease. In addition, the inspections done four times during the quarantine period of up to one year for the incoming eggs would not detect the presence of an as yet undiscovered pathogen (Paone 2000). And the potential for transfer of disease through the interior of the egg causes concern to some experts – "The potential for pathogen transmission via eggs is particularly disturbing." (Hindar 2001)

In various parts of the world, the movement of fish from one region to another has been associated with changes in the occurrence of disease in native fish stocks (Stephen and Iwama 1997). In the United States Pacific Northwest, whirling disease is an exotic parasite thought to have arrived in transfers of cultured (hatchery and commercial) trout (Nehring and Walker 1996). IHN was shown to have been transferred between continents via eggs (McDaniel et al. in Nash 2001).

Four cases of pathogen transfer that are frequently used as examples are summarized below.

Furunculosis from Denmark and Scotland to Norway

Atlantic salmon smolts imported into Norway from Scotland introduced furunculosis to Norwegian salmon farms in 1985 (Heggberget et al. 1993), eventually causing severe damage to both farmed and wild populations (Scottish Executive 2002). The infection spread rapidly between 1985 and 1992 to reach 70% of the total farms. Escaped farm fish spread the disease to wild fish and by 1992 it was registered in 74 Norwegian rivers, with epidemic proportions in four (Hindar 2001, Johnsen and Jensen 1994). The disease had been detected previously (in 1964) and found in wild Atlantic salmon in one river in 1996, so aquaculture may have increased the distribution and transmission of the disease rather than introduced it as a completely new disease. "Rapid spread of the disease was associated with several factors including escapes from fish farms, possibly via transport of fish between farms, and natural movement of wild fish in the sea." (Johnsen and Jensen 1994, p.47)

Infectious salmon anemia from Norway to other countries

Infectious salmon anemia (ISA) was first detected on Norwegian salmon farms in 1984. The virus caused significant damage to salmon farms there in the early 1990s. ISA was thought to be specific to that region until the virus started appearing in New Brunswick in 1996. The New Brunswick government ordered two million farmed fish to be slaughtered to prevent its spread. In October 1999 ISA was detected in wild Atlantic salmon in a New Brunswick river (Magaguadavic River), and the disease has spread to Maine. There have also been outbreaks of ISA in Scotland, Chile and the Faroe Islands. In Scotland, the disease problem was serious enough for government to call for a quarantine of one quarter of the country's fish farms.

Direct evidence does not exist to confirm that ISA was transferred through salmon farming for all of the above cases. It is possible that the virus existed before salmon farming but had not been detected in some instances. For example, because the mortality rates and symptoms of ISA in New Brunswick differ from those in Norway, it is possible that ISA may be a different strain that was latent within other fish species or may be a mutant of an existing non-pathogenic virus (Alaska Department of Fish and Game 2001). Critics of the salmon farming industry do not take comfort in this hypothesis: "Although ISA has never been detected in B.C., conservationists and environmentalists speculated that it was only a matter of time before there is an outbreak in that province; this is because the disease is found in every country from which Canada imports Atlantic salmon eggs." (Standing Senate Committee on Fisheries 2001b, p.17)

Gyrodactylus salaris from Sweden to Norway

The freshwater parasite *Gyrodactylus salaris* was accidentally imported to a central federal hatchery in Norway from Swedish hatcheries on the Baltic Sea through juvenile Atlantic salmon. The parasite spread through distribution of Atlantic salmon juveniles to other hatcheries and rivers. The aim was to re-introduce stocks to Norwegian watersheds which were depleted of fish. In addition to intentional transport and release of smolts for stock enhancement, unintentional releases of infected smolts through aquaculture helped to spread the parasite (Hindar 2001).

The Norwegian government deliberately poisoned some 24 rivers with rotenone in order to eradicate the parasite. This treatment also kills all aerobically respiring invertebrates (most insect larvae) and all other fish in addition to the salmonids. The parasite has either not been exterminated or has recolonized three rotenone treated rivers (Bakke and Harris 1998).

Infectious Haematopoietic Necrosis from Alaska to Japan

The viral pathogen IHN was introduced to Japan from a shipment of infected sockeye salmon eggs from a hatchery in Alaska. The disease caused epizootics in Japanese chum salmon and other salmonids (McDaniel et al. in Nash 2001).

3.5.2 Will "new" diseases keep emerging?

Point of view: If diseases are not "imported" from other regions, the diseases that appear to emerge here will already have been present in the wild.

Care must be taken in distinguishing exotic agents from newly described indigenous microbes. It is a common occurrence in new forms of fish culture to discover pathogens that in fact preexisted the activity. Previously unrecognized diseases can be observed when an organism is reared under new environmental conditions, and fish in net pens are under relatively intense and continuous observation, increasing the chances that diseases will be observed at the farm site. Kent (1998) states that because net pen salmon farming is a relatively recent form of aquaculture, it is not surprising that many "new" diseases have been documented in pen-reared salmon, and it is very likely that more diseases will be observed. The difficulty may lie in establishing the occurrence of the pathogen in the wild. The Business Case for the National Aquatic Animal Health Program recognizes "the need for emergency measures to rapidly contain and manage significant new diseases which continue to emerge in aquatic animals (predominantly aquaculture animals) in Canada and worldwide." (CAIA 2002, p.5)

Point of view: It is possible that new strains of diseases could develop.

Concerns have been raised that even if salmon farming does not introduce entirely new diseases, it could lead to variant strains of existing diseases:

> "Although these fish pathogens [reported in farmed salmon] are indigenous, there is always some risk of disseminating different or new strains of the same pathogens by farmed salmon. These other strains, perhaps more virulent, could infect new host species." (Alaska Department of Fish and Game 2001)
>
> "A most worrying aspect of *A. salmonicida* [furunculosis] is its propensity to transfer plasmids conferring drug resistance between strains. … Sakai (1987) has noted exchange of protease genes between pathogenic and nonpathogenic strains, under circumstances similar to those occurring in river sediments. Since protease phenotype is an important determinant of virulence in *A. salmonicida*, this is clearly a potential source of new, genetically and ecologically distant strains of the pathogen which could possible infect wild salmon populations." (Bakke and Harris 1998, p.252)

On this possibility, McVicar points out that there has been no evidence of changes in pathogenicity of infective agents occurring and spreading to local wild stocks and concludes that currently available evidence suggests there is limited opportunity for a farmer to substantially affect risks to wild stocks from changes in disease characteristics in farms (1998b). Consistent with this observation, Stephen (pers. comm. 2002) explains that bacteria can exchange genetic material such as plasmids. This material can affect various traits, including the bacteria's ability to live in particular environments, its ability to cause infection and/or its resistance to antibiotics. Some traits are of no particular advantage or disadvantage, and the transfer may or may not cause a new trait of concern such as virulence. In evolutionary terms, it is not necessarily advantageous for a pathogen to become more virulent because lethal effects could lead to a shortage of potential hosts for the virus.

With regard to viruses, if two strains hook onto a cell at the same time, a combination could result that leads to a new strain, but the vast majority of combinations are non-viable (Stephen, pers. comm. 2002). Nevertheless, new strains of viruses do evolve through mutation, and where there is amplification of viruses, as on a salmon farm, there is more opportunity for such evolution to occur. The mutations may be neutral or more or less virulent.

As in the case of the introduction of exotic diseases through salmon farming, the probability of the introduction of new, more virulent strains of pathogens appears to be low, but not zero.

3.5.3 Do conditions on farms weaken the health of farmed fish, increasing the chances that farmed fish will carry infections?

Point of view: Netcage salmon are under stress and therefore more susceptible to infection and disease.

The culturing of fish in a net pen can be a significant risk factor for infectious diseases, for two main reasons. First, the proximity of the fish in the pens increases their exposure to a variety of pathogens, toxins and parasites. This factor is discussed further in Section 3.5.4. Second, the stresses created by captive rearing provide an environment that can favour the occurrence of disease in farmed fish (Stephen and Iwama 1997).

As noted earlier, the propensity of fish to become diseased as a result of exposure to pathogens is strongly affected by the degree of stress they are under. Some stressors are associated with husbandry, and some are environmental – with interactions between the two sources. The impact of these stressors will vary with the age and species of the fish.

Sources of stress on salmon farms can include (note that this is not an exhaustive list):

- crowding/density make fish more susceptible to illness as stress suppresses immune response capabilities;
- territorial and social behavior under conditions of high density, such as competition for food;
- traumatic injury to the skin of the fish, including loss of mucus layer, loss of scales and open lesions or abrasions that may facilitate entry of pathogens;

- vaccine adhesions;
- poor feeding (e.g. loss of appetite when medicines are added to the food);
- feed quality issues (e.g. rancidity, vitamin loss);
- confinement (which means that the fish cannot take actions to relieve stressors such as poor water quality);
- transportation and handling (i.e. grading, splitting, harvesting);
- poor water quality (e.g., acidity, low dissolved oxygen – which can also be affected by density of fish), and phytoplankton blooms;
- water temperature change; and
- possibly interactions with predators.

Fish may become habituated to the net pen setting and otherwise adapt to the stressors at the farm. But despite this acclimatization, the stressors are still present and likely to have some impact (McKinley, pers. comm. 2002).

Wild fish, too, are subject to stress, as discussed below. Nevertheless, most published studies conclude that the stress of factors associated with netcage salmon farming, together with the increased exposure to pathogens due to the density of the farmed fish, are likely to make the environment in a farm setting more conducive to pathogen survival and propagation than the more open setting of most wild fish habitat (St-Hilaire et al. 1998).

Point of view: The health of farm fish stocks is a top priority and farm salmon are therefore kept healthy through farming practices.

It is in the economic interests of the fish farmer to reduce the risk of infection: "Healthy fish are an absolute requirement for a productive farm site and good-quality products. The health of their stocks is therefore a top priority for B.C.'s salmon farmers" (BCSFA 2002). The industry claims some success as a result of improvements in fish husbandry, including the development and widespread use of vaccines. The health of farmed salmon has improved over time, and saltwater survival of Atlantic salmon is now 95% or greater (Brackett 2001).

Because few drugs are available for treatment of disease in pen-reared salmonids, in managing salmon farming to promote fish health, prevention of disease is the preferred option, followed by early detection and diagnosis, and early intervention.

Prevention focuses on reducing stock susceptibility to pathogens, e.g., through broodstock management, vaccines, and stress reduction to improve the overall health status of the fish. In the words of an industry spokesperson: "We will only control furunculosis, IHN, sea lice, or whatever else the wild salmon throw at us, if we grow our fish properly. We cannot expect vaccines or antibiotics to do our work for us." (Needham 1995, p.29) The Salmon Aquaculture Review emphasized the importance of "a proactive policy of prevention" (Environmental Assessment Office 1997).

Intervention typically focuses on disease treatment and limitation of consequences. Both prevention and intervention can work to reduce exposure of the fish to pathogens, lessening the risk of infection. Note that Section 3.2.3 covers various ways of lessening exposure to sea lice, which may also reduce exposure to other pathogens.

Measures to prevent the exposure of farmed fish to pathogens discussed in other sections of this report include biosecurity (adherence to hygiene and disinfection protocols), siting farms away from risk factors, site fallowing between crops of salmon, single bay management and dedication of sites to single year classes.

The main approaches to health management are discussed below.

Broodstock management and disease screening

Many diseases that affect fish in net pens originate in fresh water (e.g., furunculosis and bacterial kidney disease) (Kent 1998a). Ways to avoid the introduction of pathogens to net pens include screening of broodstock for disease, disinfection of eggs, identifying fish in fresh water that have subclinical infections, and taking care to hatch and grow juveniles in facilities where contact with fish pathogens found in the natural environment is limited. Precautionary measures regarding the eggs imported for salmon aquaculture in B.C. are discussed in Section 3.5.1.

Selective breeding for disease resistance and selection of good-performing stocks are other efforts made prior to grow-out to increase overall health. The former has been of limited success to date.

Vaccines

Vaccines to prevent certain bacterial infections are injected into juvenile fish individually at the hatchery before they are transported to the ocean. Work is underway to develop several new vaccines for various other bacteria and some viruses. Increased use of vaccines will lessen dependence on antibiotic use; however, the protection provided by vaccines can be overwhelmed if fish are exposed to large challenges or are immunologically compromised (Brackett and Karreman 1998). Furthermore, the development of vaccines has proven difficult, and the costs may be too high relative to the benefits likely to be gained.

See sections 3.3.3 and 3.4.3 for discussion of vaccines in the control of bacteria and viruses, respectively.

Stress reduction

Possible stressors to farmed salmon are listed above. Wild salmon stressors are discussed in Section 3.5.4. Noakes et al. (2000, p.380) state, "There is no evidence to support the assertion that farmed fish are more stressed than the 'fight or flee' world of wild salmon." Arguments supporting the possibility of lower levels of stress in farmed salmon include:

- Domestication of stocks through selection of strains and families for desirable farm traits, and the use of fish stocks adapted to captivity, has increased the adaptability of farmed fish to farm conditions.
- Animals will adapt to the environment that they are in. They can become acclimatized to different habitat or temperatures, and habituated to conditions of higher density.

- Fish naturally form dense schools, and use only a small portion of the available space in the pen. If they were too crowded, they would more evenly distribute through the pen.
- The fish in pens do not touch each other enough to rub off mucus or scales, though fin damage is not uncommon. The fish arriving at the packing plants are generally as smooth and shiny as wild fish.

Much research has been undertaken on fish stress because its role in disease outbreaks makes it a major factor in fish health. "Better understanding of fish behaviour has led to stress reduction, and indicators of stress allow farmers to detect stress and seek its causes before disease occurs." (Gallaugher and Orr 2000, p.56) Specific ways in which salmon farming practices strive to reduce stress include: careful positioning of farms in areas with good water exchange; barriers such as predator nets, shark guards and bird nets; improved handling procedures; and improved feed quality and palatability, and feeding techniques.

Early detection

Early detection of disease to prevent the spread of infection is pursued through regular testing and field observation. "Fish are observed on an at least daily basis by farm staff. Observations of behaviour, morbidity and mortality are recorded." (Brackett 2001) Dead fish are collected and sampled to determine levels of infection, and other health indicators. Through this monitoring, changes from "baseline" mortality rates should be identified quickly and the appropriate response initiated (Brackett and Karreman 1998). Actions are triggered when preset threshold levels of morbidity/mortality are met, or by unusual events.

The farm manager also regularly samples the water for plankton, salinity and temperature. Results of monitoring are used to establish fish health management programs for the farms as well as for early detection. This supports the control of disease transfer, and the early treatment of seasonal disease events such as sea lice infestations and bacterial kidney disease (Brackett 2001).

Although fish in net pens are easy to observe compared with wild fish, there are challenges to early detection. Due to poor water visibility, it may be difficult to detect subtle external lesions on fish or behavioral changes that indicate the onset of disease. Dead fish that accumulate at the bottom of the net are not detected until collected by divers or by raising the net. Finally, some fish farmers consider a certain low-level of mortality acceptable, and losses are ignored, when these fish should be examined for incipient disease. As a result, by the time a disease problem is recognized by the fish farmer, the disease may have advanced to a stage where, even with immediate action, high mortality is unavoidable (Kent 1998a).

Treatment of disease through therapeutants

If left untreated, infectious diseases can compromise the health of the fish or cause mortalities. Therefore, if preventive health strategies have failed to prevent an outbreak – at least for bacteria and parasites – therapeutant treatments may be employed. Treatments for sea lice are discussed in Section 3.2.3, and the use of antibiotics to combat bacterial disease is discussed in Section 3.3.3. The salmon farming industry emphasizes that only a limited number of preparations are available to fish farmers to prevent or treat disease or to eliminate parasites, that medicines are prescription-only, and that they are applied under strictly controlled conditions – in line with regulatory authority rules and recommendations – and under the supervision of veterinarians (Nutreco 2001).

Treatments are administered through specially-made feed, with medication coating and/or inside the pellets. The prescriptions for the medicine go to the feed mill where it is added to the feed.

Industry interests in Canada argue that compared to other countries (e.g., Norway, Japan), the number of government-approved chemotherapeutants is very limited, restricting the ability of salmon farmers to treat disease effectively once it occurs (Standing Senate Committee on Fisheries 2001b).

Therapeutant treatments have costs. These include the cost of the medication including milling and transport, decreased feeding and growth of the fish while undergoing treatment, and the need for withdrawal or drug free period prior to harvest.

Limitation of consequences

Measures other than therapeutants to limit the effects of infections at farm sites include decreasing density, stopping feeding, and otherwise reducing stress.

One of eight elements of the Business Case in support of a National Aquatic Animal Health Program is "Response to Diseases of Concern." This emphasizes rapid detection, reporting and implementation of management actions to prevent spread of infectious disease. Measures that can be taken include quarantine, isolation, stock destruction, facility disinfection, and fallowing of infected sites (Canadian Aquaculture Industry Alliance 2002). Early harvest is another option if the affected population is marketable.

When a disease has been diagnosed at a farm, three main approaches are taken to limiting its spread: collection and disposal of mortalities (or "morts") – fish that have died from disease, isolation of the infected site and culling or destruction of diseased or infectious fish.

Controversy surrounds the collection and disposal of mortalities. Collection of dead or dying fish is by diving – usually – or by pulling up the net to get at the fish at the bottom. Frequent collection of dead fish from net pens is important to control disease, reducing pathogen loading in the net pen environment. Brackett and Karreman (1998) advise that dead fish should be removed at least weekly, and more frequently if numbers of mortalities increase. Some feel that the fish are not collected frequently enough, and/or are not tested for disease soon enough after collection (GSA 1997). Problems associated with the disposal of mortalities, such as the spread of pathogens through the water and via the equipment involved, are discussed in Section 5.2.1.

Routine measures for hygiene and sterilization – biosecurity – are stepped up to the level of "facility isolation" during a disease outbreak (in lieu of quarantine, which is not possible with net pen technology). Biosecurity and isolation protocols are discussed in Section 3.4.3, in the context of the control of viral diseases. A study of the recent spread of IHN between farms in B.C. shows that these measures are fallible.

The IHN case study also highlighted issues around the destruction of diseased fish. Concerns about the cost of lost fish often drive salmon farm companies to keep diseased fish in their net pens until they are large enough to harvest, prolonging the period during which pathogens can be shed into the environment and passing fish can be infected.

A recommendation from SAR was to strengthen regulation of quarantines and the destruction of diseased fish (Environmental Assessment Office 1997).

3.5.4 Are wild fish more exposed to enzootic (indigenous) pathogens as a result of salmon farming?

Point of view: Wild fish themselves are challenged by many enzootic pathogens and are subject to many sources of stress regardless of the presence of salmon farms.

The pathogens of concern to wild and farmed salmon are widespread geographically. Although Pacific salmon typically co-exist with enzootic pathogens, they do succumb to disease in their natural environment from time to time. In terms of life stage, they are more susceptible at spawning and smoltification, and the concentration of fish at the time of spawning and out-migration can enhance the spread of infection. Like farmed salmon, they are generally more susceptible when under stress.

Sources of stress in the wild include:

- thermal stress from water temperatures in rivers during migration and/or rapid changes in water temperature;
- lack of suitable freshwater habitat;
- variations in climate (regime changes) which influence feeding opportunities and other factors;
- poor feeding opportunities leading to poor nutrition;
- inter-species competition;
- poor water quality (e.g., acidity, low dissolved oxygen, particulates);
- trauma (e.g., open lesions or abrasions that may facilitate entry of pathogens);
- predator-prey interaction.

Beamish et al. (1999) elaborate on the role of "regime shifts" in salmon abundance and they warn of the potential to mistake fluctuations in populations caused by a regime shift as being caused by other factors such as fishing effects. Errors could also be made in this context if analysis of time series data does not take into account changes in conditions caused by trends in climate.

Point of view: Wild fish tend to resist diseases from enzootic pathogens in the ocean environment but they are exposed to new reservoirs of pathogens in salmon farms.

Lower mortality from pathogens in the ocean environment

Although dozens of pathogens challenge wild salmon in their natural environment, and wild salmon do encounter many stressors, mortality from disease is not necessarily high in the wild. Mutual adaptation through evolution has allowed species to coexist. "Thus it is unusual for serious pathogenicity or epidemics to occur in natural conditions." (McVicar 1998b) Even though wild salmon may be infected with a greater variety of pathogens compared to farmed fish there appears to be fewer disease outbreaks or epidemics with significant mortality (Saunders 1991, St-Hilaire et al. 1998). Under balanced conditions and usually at low densities, in nature most pathogens are held in check (Saunders 1991). The transmission of more pathogenic viruses is restricted to the extent that there will be fewer infected carriers of the disease if the hosts are killed by the virus. The low density of salmon at sea also constrains disease transfer (Bakke and Harris 1998).

Amplification of pathogens in the net pen, acting as disease reservoirs

All of the diseases found on salmon farms are considered enzootic to B.C. If enzootic pathogens are not a significant threat to wild salmon in the absence of salmon farms, how can the farms pose a potential threat? The theory is that the farms amplify (increase the concentration of) the pathogens, and act as a new reservoir for pathogens to which wild salmon are exposed through the water column as they move around or past the farms. "There is no evidence that this happens but it is plausible and there is no reason to think that it might not happen." (Gallaugher and Orr 2000, p.55)

The pieces of the puzzle that make the establishment of disease reservoirs at salmon farms a real possibility are:

- On farms, antibiotics keep fish alive, and so they remain in an infectious state as carriers of the disease (Morton 1995).
- "Introduced fish [like Atlantic salmon in B.C.] may … form a highly susceptible resource for the multiplication of native parasites [including viruses and bacteria] normally found [at non-pathogenic levels] in other fishes." (Bakke and Harris 1998, p.257)
- Density in confined conditions enhances the frequency of interaction between pathogen and host, increasing the probability of effective contact, thus causing disease to spread rapidly in captive populations once it occurs (Brackett and Karreman 1998, p.10).

Note that the impact of these factors can be reduced by keeping farmed fish healthy, as discussed in Section 3.5.3, above. However, the above factors still hold the potential to amplify whatever levels of pathogen may occur at the farm site. In short, "Salmonid farms can have profound effects on the abundance of [pathogens] around them." (Bakke and Harris 1998, p.258)

Other conditions related to the interactions of pathogen, host and environment have to be met for wild salmon to become diseased as a result of exposure to this reservoir. One is that the wild salmon likely have to be stressed (they are otherwise resistant to enzootic pathogens). Factors that can cause stress in wild salmon are discussed above. A second condition is that the wild salmon have to have effective contact with the pathogens (albeit with a starting probability that is higher because of the presence of the reservoir). Once a disease is developed within the farm it may be transferred into the wild through escaped fish, through feces surrounding the farm, by boats and equipment, by water used in transport or processing, or from the diseased fish in the net pen to wild fish through seawater. The latter mechanism is described here, with the others having been addressed in other sections of this report.

Spread of pathogens through the water

Inherent to netcage technology is the uncontrolled exchange of water between the pen or net cage and the surrounding waters. Permeable nets allow the water carrying pathogens within the pen to mix with water outside the pen. (Through the reverse process, wild fish infect farm fish.) This movement of water will be influenced by tidal flushing, which can enhance transfer by transporting the pathogens but can also reduce the likelihood of effective contact by diluting the pathogen.

Location of farms is the other major variable affecting the probability of the exposure of wild fish to pathogens from the farms. Currently netcage salmon farms tend to be located along wild salmon migration routes and/or near wild salmon rivers. Bakke and Harris (1998, p.259) emphasize this factor: "Finally, we would stress again the position of marine rearing pens as pathogen culture facilities at the crossroads for migrating salmonids moving between fresh and saltwater." Not only does siting on migration routes enhance the potential for the transfer of pathogens, it increases the probability of contact with juvenile salmon at the most vulnerable stage of the ocean phase of their life cycle.

Attraction of wild fish to farms as a result of lighting

Salmon farms often are lit at night by submerged lights which encourage feeding. This is also known as "pitlamping," or, more technically, as "photostimulation" of juvenile salmonid growth. There have been reports that the light attracts wild salmon smolts and herring (Iwama et al. 1997, Musgamagw Tsawataineuk Tribal Council, n.d., GSA 1997, Appendix 1, Keller and Leslie 1996). These fish then can be more exposed to pathogens from the farms. Related concerns are the potential eating of the wild fish that enter the nets by the farm fish, effects on local plankton populations, and the attraction of salmon lice to the light (Iwama et al. 1997).

3.5.5 *Is there evidence that diseases are transferred from salmon farms to wild stocks?*

Point of view: There is no direct evidence of disease transfer to wild salmon that would constitute "proof" to the highest standard of scientific scrutiny.

It is generally agreed that there is no proven, direct link in the spread of disease from farmed salmon to wild salmon in British Columbia. As stated earlier, in the case of viruses, "The potential exists for transfer of infectious diseases such as ISA … from farmed to wild stocks but the real level of risk is not quantifiable given present knowledge." (Scottish Executive 2002, p.26) In other words, the movement of pathogens from farm to wild fish has not been proven directly.

The lack of direct evidence is true in other regions as well as B.C. Where salmon culture has apparently introduced disease to wild fish, as with *Gyrodactylus salaris* in Norway, the disease in question was imported to the area rather than enzootic. In 1990 Windsor and Hutchinson stated "… there are no documented cases of mariculture leading to increased incidence of disease in wild fish by a pathogen already present in the environment." (p.169) This statement is still accurate today, according to the literature reviewed for this report, if the strict criteria for causality are applied. Individual incidences of disease transfer have been reported outside of B.C., but no measurable effects on incidence of disease in wild fish populations has been determined. (In Norway, furunculosis introduced from Scotland did apparently transfer from farmed to wild fish, and in Scotland, infectious pancreatic necrosis was reported to have spread from farmed to wild fish. However, in both cases, there was already a low prevalence and limited distribution of the virus in wild fish and the infection appeared to be 'inactivated' within a short distance of the farm (Windsor and Hutchinson 1990, p.168)).

Point of view: Circumstantial evidence strongly suggests that disease transfer has occurred, especially in the case of sea lice.

The next section summarizes the serious lack of knowledge needed to rigorously prove or disprove a connection between disease in salmon farming and health of wild salmon. Even in principle, it will be difficult to ascertain whether a pathogen has been transferred from farmed fish to wild stocks and has resulted in increased disease. First, it must be shown that there has been an increase in a specific disease in the stock in question. Then, a causal relationship between any confirmed increase in the prevalence of a disease in a wild population with salmon farming would have to be established, meeting scientific standards such as Hill's Criteria (see Section 3.1). It has been argued, however, that although causation is difficult to prove, disease potential stemming from situations that do not meet these criteria should not be ignored (Bakke and Harris 1998).

We do know that wild and farmed fish are exposed to and can be infected by many of the same pathogens. We know that farmed fish have diseases resulting from exposure to pathogens from wild fish. Since pathogen transfer is a two-way phenomenon, it is then possible for wild fish to have diseases resulting from exposure to pathogens from farm fish. It is also the case that there is no evidence that diseases are *not* transferred from farm salmon to wild salmon. "The potential for bacterial and viral diseases to be transmitted from farmed fish to wild is real." (Scottish Executive 2002, p.26)

While proof to the highest standards of scientific accuracy is lacking, circumstantial evidence, especially for sea lice transfer, is compelling, and continues to accumulate. Temporal and spatial associations between lice on farms and increases of sea lice on wild salmon are strong; our increasing understanding of the role of lice in fish health suggests that causal connections are possible; and alternative theoretical explanations for increased lice on wild salmon in the vicinity of salmon farms do not appear to be as plausible as the explanation of lice transfer from farms. In the case of sea lice transfer, at least five criteria out of Hill's nine criteria appear to be met (see Section 3.2.5). Meeting all nine criteria is likely not feasible, and the lack of "proof" to this degree of rigor should not be used as a reason to delay action.

3.6 Gaps in our understanding of disease issues

A report to DFO evaluating knowledge and gaps related to impacts of aquaculture on the aquatic environment (EVS 2000) observed that most studies related to disease and fish farming are about the pathogenicity of diseases affecting aquaculture and that few studies have focused on assessing the transfer of disease to wild salmon populations. A multi-interest workshop at Simon Fraser University concluded that a focus on ways of improving the health of farmed salmon "serves the industry and preserves the health of wild fish at the same time." (Gallaugher and Orr 2000, p.55) Thus, although a considerable amount of research has been conducted on disease in aquaculture, more work is required to fully understand the ecological ramifications of these diseases and their transfer to wild stocks (EVS 2000).

Most literature predominantly pertains to experience of disease in aquaculture in Europe rather than Canada. Yet even internationally, the study of transmission of diseases in wild salmon populations is in its infancy. "In particular an ecological focus on salmonid disease is almost entirely lacking." (Bakke and Harris 1998, p.259) A recent government report from Scotland asserted, "Further work is required to determine the factors affecting the risk of transmission of a variety of fish diseases between farmed and wild populations." (Scottish Executive 2002, p.27)

In 2000, the Canadian Auditor-General found that there is "a serious lack of information" about the possibility of disease transfer from farmed to wild salmon populations – "The Department [of Fisheries and Oceans] acknowledges that it does not have enough information available to assess the risk of disease transfer from farmed salmon to wild stocks." The Auditor-General concluded, "Further research is needed into the effects on the health of wild salmon stocks." (Desautels 2000, p.30-19) Last year, the Senate's Standing Committee on Fisheries similarly recommended that the federal government invest more research resources to: "determine the probability of disease and parasite transfer between cultured salmon and wild fish." (2001c, p.73)

Undertaking the recommended research will be no simple task. Two key challenges make definitive conclusions on a causal link in the transfer of infectious disease between farmed and wild salmon in B.C. difficult. First, we lack sufficient data on "normal" disease levels in wild salmon. Before considering the complex questions that surround disease transfer processes, we need at least a fundamental understanding of natural levels of disease and pathogens in wild fish. We know something about diseases in wild salmon in B.C. through reports from fishermen, records from enhancement hatcheries, and emerging research, but information is otherwise lacking on disease processes in wild fish.

Second, because all of the diseases seen on salmon farms to date are also found in the wild, it is difficult to distinguish natural occurrence of disease in wild populations from disease originating from salmon farms. How much more disease in wild salmon is being caused by salmon farms as compared to levels of disease that would be present naturally?

Several other challenges confront the research effort, including the following.

- Wild fish are difficult to track in the marine environment when they are diseased. Diseased fish often do not survive long in the wild since, in their weakened state, they are easily consumed by predators. Even infected fish may die and disappear before they can be detected.

- Because of the complex life cycle of the salmon, scientists may have to follow a cohort of wild salmon through a full generation – up to several years – to determine if they have been impacted by factors resulting from a given level of aquaculture production (Whoriskey 2000b).
- Variations in the pathophysiology of wild species, and the complex interactions of environmental, ecological and microbiological factors in nature present significant sources of uncertainty (Stephen and Iwama 1997).
- Differences between strains and species complicate efforts to generalize research results (Stephen and Iwama 1997).

Extensive research will be required to establish the extent of the connection between disease in farmed salmon and disease in wild salmon populations to the highest standards of scientific scrutiny. Following is a list of research initiatives that have been suggested by various experts:

- Monitor wild populations to investigate prevalence and range of diseases and to identify as yet unknown pathogens that exist in the wild. (This could also help in the management of wild fisheries.)
- Establish the source of indigenous pathogens.
- Develop methods to detect changes in the level of disease in either population – farmed or wild.
- Establish a structured disease surveillance program to determine relationships in the transmission of disease between farmed and wild salmon.
- Gather information about the ecology of sea cages.
- Identify wild species that are at highest risk of encountering health threats of salmon farm origin.
- Investigate the role of disease in early life cycle stages (fry and parr) and on events during the marine phase.

3.7 Assessing the risks to wild salmon posed by diseases from salmon farms

Until research is completed leading to more definitive understandings, likelihood and consequences of disease transfer to wild fish can only be discussed in terms of risk. We cannot, at present, be certain about the nature, extent and impacts of disease transfer, but we can qualitatively estimate the risks involved.

Conclusions on the risks posed to wild salmon by disease transfer from salmon farms are summarized below in terms of: theoretical risks; risks pertaining to sea lice, bacteria and viruses; and risks associated with over-arching issues in disease transfer.

3.7.1 Theoretical risk of disease transfer from farmed to wild salmon

In the context of disease, the level of risk will be driven by certain principles, as introduced at the beginning of this chapter. To review, for farms to increase disease outbreaks in wild salmon, the number of susceptible individuals or the probability of contact have to increase. Aquaculture cannot increase the number of susceptible wild salmon, so the focus falls on the probability of contacting an infectious individual (and effective exposure). This probability is in turn affected by the following principles, which were introduced at the outset:

- Different species are susceptible/resistant to different diseases.
- Susceptibility is affected by life stage.
- Susceptibility is also affected by stress factors.
- Pathogens have a range of characteristics.
- Pathogens can be transmitted in a variety of ways.
- Fish must be exposed to the pathogen to acquire the associated disease.
- Fish can come into contact with pathogens without becoming infected, can be infected without becoming diseased, can be diseased without dying, or can die from infectious disease.

Accordingly, for a serious infection of a wild salmon stock or population to occur as a result of pathogen transfer from farms, a number of processes would have to coincide. The following circumstances would maximize the potential for disease transfer to wild salmon:

- the presence of wild salmon species, susceptible to a pathogen based on their species and life stage, in the vicinity of the salmon farm;
- environmental conditions such as pollution and temperature change that increase the susceptibility of wild salmon to disease by causing stress;
- presence of pathogens to which the wild salmon are susceptible and which have the potential to survive away from the farm fish host long enough to transfer to the wild fish host;
- conditions at the farm that cause stress or otherwise increase the numbers of infected fish at the farm (e.g. failure of biosecurity measures), expanding the reservoir to which the wild salmon could be exposed;
- lack of dilution of pathogens by tidal action (maintaining sufficient density/quantity for effective exposure);
- environmental conditions such as salinity, temperature and currents that increase the survival and transference of the pathogens.

Not *all* of these factors have to co-exist for disease transfer to occur. Despite the apparent complexity of these theoretical "pre-requisites," scenarios for serious impact on wild salmon are conceivable. Furthermore, the large gaps in our knowledge base allow no certainty that the appropriate circumstances will not converge.

3.7.2 Summary of risks posed by sea lice, bacteria and viruses

Sea lice

Causality in the spread of sea lice from farmed fish to wild fish in British Columbia has not yet been proven to the highest standard of scientific scrutiny. However, the combination of scientific results from Europe (European Commission 2002, Scottish Executive 2002), preliminary studies of lice on juvenile salmon in B.C. and knowledge of sea lice-salmon dynamics presents a body of compelling evidence that sea lice from salmon farms do impact wild salmon. The main areas of uncertainty relate to how large or severe impacts will be, rather than to whether or not they will occur. McVicar, summarizing a 1996 ICES workshop on sea lice, concluded that "lice from salmon farms will contribute to lice populations in wild salmonids, but the extent and consequences of this have not been quantified." (McVicar 1997, p.1101)

Improvements in fish health management at the farms will reduce but not eliminate the potential for farms to transfer lice to wild salmon. Despite the natural prevalence of sea lice, wild salmon are vulnerable to them. In heavy infections, death results from erosion of the skin of the fish. Other possible consequences include premature return to spawning and reduced seawater growth. Indirect effects associated with disease transfer via lice could be an emerging issue of concern.

Sea lice are the most serious, immediate risk out of the three fish health issues considered in this report (parasites, bacteria and viruses).

Bacteria

Wild Pacific salmon are somewhat vulnerable to pathogenic infections from bacteria even though they generally are well adapted to the bacteria found in B.C.'s coastal waters. Concern over the potential for transfer of furunculosis from farmed to wild salmon is warranted despite the lack of direct evidence, but the effective use of vaccines substantially reduces the risk. Antibiotic resistance caused by the use of antibiotics on salmon farms does not appear to create risks to wild salmon. Bacteria pose the lowest risk to wild salmon, among the three fish health issues considered.

Viruses

The potential for farm sources of viral pathogens to increase infection of wild fish is reduced by the natural resistance of Pacific salmon to enzootic viruses. As well, the literature does not provide evidence of viruses that have caused problems at farms having negative effects on wild salmon. Nevertheless, migrating salmon could be exposed to viruses such as infectious hematopoietic necrosis (IHN) from farms at levels higher than those to which they are accustomed; and in other jurisdictions, infectious salmon anaemia (ISA) has been found to transfer from farms to wild fish. The risk that the exposure will be effective enough to cause infection increases when farm sites provide a reservoir for the virus, especially if diseased fish are not culled. Good husbandry and lower stocking densities on the farms can reduce the threat that salmon farms will act as reservoirs of viruses by making farm fish less vulnerable to infection; however, these efforts are currently limited by the lack of effective treatments for viruses. The level of risk posed to wild salmon by viruses of farm origin is intermediate to the higher risk from sea lice and the lower risk from bacteria.

3.7.3 Summary of over-arching issues in the potential for disease transfer between salmon farms and wild salmon

Format of issue review

Issues in the potential for disease transfer between salmon farms and wild salmon as analysed in Section 3.5 are summarized below in the following format:

Issue: Re-statement of the question

⇓ Risk viewpoint: This is a summary of the point of view supporting a lower risk of impacts on wild salmon from salmon farming.

⇑ Risk viewpoint: This is a summary of the point of view supporting a higher risk of impacts on wild salmon from salmon farming.

Best estimate: This is a statement of the risk based on a consideration of the strengths and weaknesses of each argument.

Issue: **Are exotic diseases likely to be imported to B.C. through salmon farming?**

⇓ Risk viewpoint: No exotic diseases have been imported to B.C. as a result of salmon farming.

⇑ Risk viewpoint: Exotic diseases could be imported by salmon farming practices, as has occurred in other places.

Best estimate: The introduction of exotic diseases to B.C. through salmon farming could have severe – even irreversible – consequences for wild salmon stocks. Preventive measures have made the probability of this low; however the risk will never be zero. Global experience shows that the introduction of exotic pathogens through fish culture is infrequent, but when it happens it can have serious consequences. Of current international concern is the ISA virus. ISA has not been detected in B.C. although it has been introduced to New Brunswick and Maine. This virus appears to have been spread between regions through fish farming practices, though no significant impacts on wild salmon have been observed.

Issue: **Will "new" diseases keep emerging?**

⇓ Risk viewpoint: If diseases are not "imported" from other regions, the diseases that appear to emerge here will already have been present in the wild.

⇑ Risk viewpoint: It is possible that new strains of diseases could develop.

Best estimate: The probability that new strains of disease will develop through salmon aquaculture (due to the use of antibiotics) and have negative impact on wild salmon appears to be low. The bacteria that are selected through antibiotics are not necessarily the hardiest representatives in a population and their numbers only become high due to the antibiotic treatment, for the period during which the antibiotic is applied. These *selected* are not newly created or mutated bacteria and they are not necessarily more virulent. However, the risk of a more virulent strain cannot be discounted. The impacts of this phenomenon, if it did occur, could be serious, although likely less catastrophic than the possible impacts of the introduction of an exotic pathogen. It is probable that previously undetected diseases that are native to this coast will be identified through outbreaks on salmon farms. The challenges will be to confirm that the pathogen does exist in wild stocks, and to ascertain the risks of biomagnification (increase through biological processes) of the pathogen in the farm context.

***Issue:* Do conditions on farms weaken the health of farmed fish, increasing the chances that farmed fish will carry infections?**

⇓ *Risk viewpoint:* The health of farm fish stocks is a top priority and farm salmon are therefore kept healthy through farming practices.

⇑ *Risk viewpoint:* Net cage salmon are under stress and therefore more susceptible to infection and disease.

Best estimate: In principle, if farms had no higher levels of pathogens than the surrounding marine environment then they would pose no incremental risk to wild salmon through disease transfer. High densities of fish in the net pens may increase susceptibility of farm fish to disease by increasing stress and will increase the probability of disease transfer among the fish in the net pen. Much progress has been made in health management in salmon farming: from vaccines through to containment of an outbreak, improved farming techniques have reduced the loss of fish to disease in salmon farms. Nevertheless, it is likely that concentrations of pathogens (most importantly, sea lice and viruses) are higher in the net pen setting than in the natural marine environment. As well, the recent IHN epidemic in B.C. demonstrated that infection can spread from farm to farm during a disease outbreak.

***Issue:* Are wild fish more exposed to enzootic (indigenous) pathogens as a result of salmon farming?**

⇓ *Risk viewpoint:* Wild fish themselves are challenged by many enzootic pathogens and are subject to many sources of stress regardless of the presence of salmon farms.

⇑ *Risk viewpoint:* Wild fish tend to resist diseases from enzootic pathogens in the ocean environment but they are exposed to new reservoirs of pathogens in salmon farms.

Best estimate: It is true that fish in the wild do face disease risks, but evolutionary processes have led to a level of immunity in wild fish to the pathogens that surround them. The question is whether the presence of disease reservoirs in fish farms offers a significantly higher possibility of effective exposure of wild fish to infectious agents. In the case of sea lice, evidence is accumulating that it does. Chances of effective contact with pathogens are further enhanced by the siting of salmon farms on the migration routes of wild salmon. Another important variable in determining the risk of effective exposure is that of the survival time of pathogens that farmed fish may shed into the water column (which may then be carried by currents) or sediments below the net pens. In the case of lice and viruses such as ISA and IHN, survival time seems sufficient to pose a significant risk. In the case of bacteria such as furunculosis, the probability appears to be lower.

Issue: **Is there evidence that diseases are transferred from salmon farms to wild stocks?**

⇓ *Risk viewpoint:* There is no direct evidence of disease transfer to wild salmon.

⇑ *Risk viewpoint:* Circumstantial evidence strongly suggests that disease transfer has occurred, especially in the case of sea lice.

Best estimate: We know that farmed fish have diseases resulting from exposure to pathogens from wild fish. Since pathogen transfer is a two-way phenomenon, it is then possible for wild fish to have diseases resulting from exposure to pathogens from farm fish. While proof to the highest standards of scientific accuracy is lacking, circumstantial evidence, especially for sea lice transfer, continues to accumulate. Temporal and spatial associations between lice on farms and increases of sea lice on wild salmon are strong; our increasing understanding of the role of lice in fish health suggests that causal connections are possible. Alternative explanations for increased lice on wild salmon in the vicinity of salmon farms do not appear to be as plausible as the explanation of lice transfer from farms. The combination of scientific results from European research, studies of lice on juvenile salmon in B.C., and knowledge of sea lice-salmon dynamics presents compelling evidence that sea lice from salmon farms do impact wild salmon. In Europe, other examples of disease transfer include furunculosis and ISA.

4 ESCAPES

It is general knowledge that some fish escape from B.C. salmon farms. What is not clear is how many fish escape, where they go or what happens to them after they escape. There is disagreement as to whether they survive in significant numbers, and whether they spawn, invade or colonize wild salmon habitat, disrupt spawning habitat, or interbreed with wild salmon. These longer-term issues, especially the question of whether escaped salmon will colonize (i.e., establish a self-reproducing natural population), are more difficult than the question of how many fish are escaping. This chapter offers some background to the escapes phenomenon, discusses three over-arching issues (genetic, ecological and disease), and then analyses a number of specific issues.

4.1 The nature of escapes

Our understanding of escapes has to be informed by recognition of the distinctions between farmed species and local wild populations of Pacific salmon, the difficulty of monitoring escapes, and the international context.

4.1.1 Issues are different for Atlantic and Pacific species.

Issues associated with Atlantic salmon or Pacific (primarily chinook) salmon escaping from B.C. netpens are different. At present the majority of production from B.C. salmon farms is Atlantic salmon (over 70%), but before 1985, Pacific salmon were initially used. Increased interest has recently been shown in chinook salmon again, largely due to their resistance to certain diseases. With Pacific salmon, the consequences of escapes interbreeding with wild salmon could be more severe than for Atlantic salmon escapes, and the difficulty of identifying escapees is much greater.

Atlantics are a non-native (exotic) species to B.C. Thus, some believe that the results of their interactions with Pacific salmon are likely to be negative and unpredictable. They cite other examples of introductions of alien species and the unforeseen – and sometimes irreversible – negative effects that have taken place after introduction and successful colonization (Carter 1998).

In the discussion of over-arching and specific issues related to escaped farmed salmon that follows, beyond the theoretical level, the analysis can only address Atlantic salmon. Escaped Pacific salmon cannot be identified at this time because without artificial markers or highly technical analysis they cannot be distinguished from wild salmon. Therefore, information on Pacific escapes and naturally spawning populations cannot be gathered. The inability to monitor escaped Pacific farmed salmon is one of the most significant limitations on our ability to assess the impacts of escapes on wild salmon.

4.1.2 Numbers of escaped salmon are difficult to determine.

Salmon escaping from netpens consist of frequent small "leakages" of smaller fish and a smaller number of large "major escape" events. The latter refers to the escape or loss of larger fish from netpens due to accidents with nets, storms, transporting fish, etc. It is not known what the total of small leakages from the 86 active farms is in any given year.

Monitoring and recovery of escaped salmon can provide only partial information and the effectiveness of monitoring is limited by a variety of factors. The monitoring and recovery programs are less successful in monitoring for escaped Pacifics than for escaped Atlantics. Gross (in Harvey and MacDuffee 2002) noted, "farmed chinook and coho are more difficult to identify and go largely unidentified in catch records." Releases of millions of hatchery-raised Pacific salmon annually complicate the analysis. Gross saw the lack of identification of escaped Pacifics as a significant gap, in that one in five B.C. escapees might be either chinook or coho.

Escapes reported by the industry

Larger losses must be reported to the Provincial government once the loss has been detected. The jointly-funded (federal/provincial) Atlantic Salmon Watch Program (ASWP) has been in effect since 1991 and maintains a record of all reported salmon escapes (Atlantic Salmon Watch 2002). Results of this program are summarized in Table 1, below. Efforts have been made to recover escapes but it is generally accepted that recovery via fishing gear is ineffective and typically only accounts for 20-30% of the estimated escapes.

Table 1: Juvenile salmon escapes from B.C. and Washington State salmon farms as recorded by the Atlantic Salmon Watch Program at the Pacific Biological Station

Data is as reported to November 2002. It does not include allowance for "leakage" of small fish from salmon farms and only includes the numbers of escaped salmon reported by the industry.

	Atlantic Salmon in B.C. and WA				Pacific Salmon in B.C.	
Year	Freshwater Juveniles	Seapen Juvenile	Seapen Adults	Washington State	Seapen Chinook	Seapen Coho
1987					22,422	
1988					2,000	
1989					392,271	
1990					165,000	
1991			6,651		229,500	
1992		5,000	4,544		59,632	
1993			10,000			12,113
1994	7,000	24,262	39,547		2,300	
1995	941		51,883		5,000	1,000
1996	40,000		13,104	101,000		
1997	10,464		7,650	369,661	38,956	
1998	300	45,306	43,208		7,000	
1999		482	35,248	115,000		
2000		1,000	36,462		31,555	
2001			29,975			
2002			8,018		3	

Source: Atlantic Salmon Watch 2002

Escapes identified by stream surveys

Sampling in rivers and streams in B.C. is conducted through the Atlantic Salmon Watch Program (Atlantic Salmon Watch 2002; Thomson and McKinnell 1993, 1994, 1995,1996, 1997; and Thomson and Candy 1998). Provincial programs (Burt et al.1992, Lough and Law 1995, Lough et al. 1996 and 1997, Volpe 1998, Volpe 1999, Volpe 2000b, Lough and Hay 2001), and the recently-instituted First Nations Atlantic Salmon Watch (First Nations Atlantic Salmon Watch 2002), have supplemented the Atlantic Salmon Watch Program. Together these programs only survey a small portion of the streams that may receive escaped salmon and have limited budgets for their efforts.

A major limitation in stream surveys is the difficulty, mentioned above, of distinguishing escaped Pacific fish from native fish. Stream survey methodology leaves still more room for variation and uncertainty. Even with training programs developed, survey variables can include diver expertise, percentage of stream covered, visibility conditions and season, and survey effort per stream. Some also say that the Atlantics seek refuge in different places than wild salmon and others note that Atlantics may hold in a river for months before spawning and may thus be counted multiple times.

See Section 4.3.5 (table 2) for data on Atlantic salmon recorded in B.C. stream surveys.

Escapes identified by fisheries

Observation of Atlantic salmon in catches occurs through existing agency sampling programs (established for managing wild Pacific salmon fisheries) or opportunistically as reported, especially from sport and Native fisheries. Reliance on the commercial or sport fishing industry to help enumerate escapes is useful, but provides only sporadic added coverage. As Noakes et al. (2000, p.375) note, "Marine recoveries are a function of both the age and number of escaped fish as well as the fishing effort in the area and the time of the escape." As commercial fishery openings decrease, the utility of this source of assistance decreases. Furthermore, it is alleged that those who catch Atlantics may not have incentive to report them, preferring to keep them for themselves (Ecological Interactions 2001). However, since 1987, about 18,800 Atlantic salmon have been reported in B.C. marine fisheries (by all gear types). An additional 591 were reported by the Alaska Department of Fish and Game (Atlantic Salmon Watch 2002). In B.C., the vast majority of these recoveries have occurred in Statistical Area 12 (upper Johnstone Strait and lower Queen Charlotte Sound) fisheries using net gears.

4.1.3 The subject has international dimensions.

In the case of Atlantic salmon escapes, B.C. numbers may be complicated by escapes from adjacent Washington State farms. This has been the case in the recent past, with some major Washington escape events in 1997 and 1999 (Ecological Interactions 2001 and Atlantic Salmon Watch 2002).

The State of Alaska has expressed concerns about escapes from B.C. salmon farms and their possible impacts on Alaskan wild salmon (Alaska Dept. of Fish and Game 2001). Until this year, the Alaskan escape monitoring effort has been relatively small. The State is now preparing to implement a new Aquatic Nuisance Species Management Plan that will expand monitoring for Atlantic salmon and a number of other species (Alaska Dept. of Fish and Game 2002).

If and when new production sites are opened in the more northerly areas of the province, it is likely that Alaska's interest in B.C. escapees will increase, because of the proximity to that state (Gaudet 2002). B.C. industry and government spokespersons discount the Alaskan concern, saying that it is largely driven by concern by that state for the competitive position of its wild salmon industry. (Note that commercial salmon net pens are not permitted in Alaska but the State is heavily involved in hatchery ocean ranching programs.)

4.1.4 Scottish and Norwegian experience may be relevant on some points.

In Norway, the farmed species and the wild species are the same, so Norwegian experience may be more relevant to the case of escaped B.C. chinook and coho salmon than to escaped Atlantic salmon. Wild Atlantic salmon populations in Norway, however, are depressed and numerically greatly exceeded by the farmed fish escapes. The Norwegian Atlantic Salmon Watch program deals with both farmed and hatchery fish, and aims to create a database for management actions to help protect wild populations. It is reported that Norwegian escapes declined significantly after farms had been relocated away from risk-prone sites (Ecological Interactions 2001).

A recent Scottish review of aquaculture also deals with many aspects of the escapes issue. In this review, the Scottish Executive concluded, in discussing environmental limitations on the scale of the Scottish marine fish farming industry, that "Escapes from salmon farms probably represent a serious threat to wild populations of salmonids… The current level of escapes is probably unsustainable in terms of the health of wild populations. It is difficult to determine how this relates to the scale of the industry, as it is clearly the scale of escapes rather than the scale of the industry that is important. Were the industry to significantly improve containment and/or reduce the fertility of farmed fish then it is obvious that escapes might then limit the scale of production to a lesser extent." (Scottish Executive 2002)

At least two points of difference limit the applicability of Scottish research and experience to B.C. As in Norway, the Scottish ratio of farmed fish escapes to wild salmon population is higher than in B.C. Second, Scottish farmed fish escapes are more numerous than hatchery fish releases (Scottish Executive 2002), while the opposite applies in B.C.

4.2 Over-arching issues in escapes

The impacts of escaped farmed fish on wild salmon can be generally classified into genetic, ecological and disease issues.

4.2.1 Genetic effects of escapes involve possible reductions in genetic diversity and fitness.

Inter-mating of farmed escapees and natural populations is one of the factors that may cause change in the genetic characteristics of the natural stock. The impact of these changes depends on the degree of genetic difference and the level of inter-mating of farmed escapees and natural populations. The genetic basis of Atlantic salmon is very different from Pacific since they are an exotic species and only distantly related to species on the west coast (with the exception of some brown trout that are also an introduced species; see Behnke 1992, Oakley and Phillips 1999). Atlantic and Pacific salmon are so different genetically (for example, in numbers of chromosomes) (Allendorf and Thorgaard 1984) that inter-specific hybrids are very unlikely. Direct tests of crossing Atlantics and Pacific salmon have not been extensive. Those that have been conducted demonstrate very low survival even during laboratory crosses. Dr. R.H. Devlin (DFO scientist, West Vancouver Laboratory) conducted the most recent study. Its results were summarized in Waknitz et al. 2002 and Noakes et al. 2000. Studies such as these suggest that the likelihood of viable hybrids between the two species is very low and not considered a serious risk. The potential mating of escaped farmed Pacific salmon with wild Pacific salmon is, however, a greater risk.

Farmed fish are often developed from a limited number of source populations, and are selected for traits that improve performance in the farm environment. As a result, genetic diversity in farmed fish decreases over time and the genetic makeup of the farmed Pacific will become different from local Pacific salmon species. Theoretically then, the interbreeding of these domesticated farm salmon with the naturally produced salmon could result in changes to the genetic composition of the local populations and a reduction in diversity if the number of escapes were significant.

The potential loss of diversity between populations of Pacific salmon is a major concern to resource managers and conservation groups. Genetic diversity in natural populations occurs within and between populations and depends on population sizes, the balance between selection for different traits in an environment and the naturally occurring number of migrants (strays) between populations. The "stock concept" of Pacific salmon (Ricker 1972) has been fundamental to salmon management for decades. It refers to the conservation of localized spawning populations that are likely adapted to the local environmental conditions (Taylor 1991). Since Pacific salmon return to their natal streams to spawn, if the movement of fish between local populations is not excessive, then these local populations can accumulate genetic differences that enhance their productivity. The diversity of these localized adaptations represents the "biological basis" for the continued evolution of Pacific salmon. A reduction in genetic variability (reduced varieties or changes to gene frequencies) may have immediate effects through reduced productivity of the natural population in its environment and, in the longer term, could reduce the ability of these populations to adapt to changes in the environment.

While the extent of genetic differences and the potential effects of escapes are debated, the basic mechanisms for interactions are not. In a report for the Office of the Commissioner for Aquaculture Development (OCAD), Peterson (1999) attempted to identify the factors that would determine the effects of intrusion of escaped farm fish into a healthy wild stock. He included "the size of the escapement [the number of fish from the farms], relative reproductive success of farmed fish that enter the spawning grounds and many other issues." He further noted "from a genetic encroachment perspective, it is not the number of escapees that is important, but the number of offspring that appear in the next generation of the wild stock." Peterson's report identifies concern for the number of fish escaping into the natural spawning population, the frequency of occurrence, and the success of the spawning of these escapes. The reproductive success of these fish will vary depending on their spawning behaviour, the extent of genetic differences between populations, and the ability of offspring to survive in the next generation.

Some points require clarification. If the reproductive success of the escapees were poor, then the immediate effect could be a loss of production in the next generation. The long-term effect, however, would be negligible since the "genetic material" would not be effectively transmitted to the next generation. However, if escapees successfully spawn with the natural population, evidence of a longer-term genetic effect could develop in the second generation due to outbreeding depression. Outbreeding depression is a loss of fitness due to the break-up of adaptive gene complexes or groups in the reassortment of genes during the formation of the second generation. It is most likely to occur when animals of different genetic backgrounds are mixed and interbreed, such as with domesticated farmed fish and wild Pacific salmon: "When farmed fish escape they can breed with wild fish; it is possible that the immediate offspring of such crosses may benefit from hybrid vigor, but this is not passed on to the next generation owing to the

phenomenon of outbreeding depression leading to much lower fitness and productivity." (Scottish Executive 2002).

It has been noted that the same possibilities exist when hatchery-produced salmon are released and allowed to interbreed with natural populations of Pacific salmon (Noakes et al. 2000, Scottish Executive 2002, Harvey and MacDuffee 2002). Fundamentally this is true, but the degree of effect depends on the parameters noted above. Farmed fish undergo genetic selection and are expected to be different from localized wild Pacific salmon. Hatchery fish are also believed to undergo domestication and would gradually come to differ from the wild populations. However, there is frequent mixing of local wild and hatchery fish. This mixing will reduce the degree of genetic differences that accumulate. Nevertheless, there is increasing evidence of differences between hatchery and wild-reared salmon. Hatcheries usually involve a continuing flow of genes between sub-populations (i.e., unintentional strays or deliberate mixing) but these animals likely have minimal genetic differences. Farmed fish enter the wild less frequently than hatchery fish, but the escapes may occur in pulses and the animals are likely to be genetically different. In combination, these latter factors make the genetic risk to wild salmon higher from escaped farmed fish. However, this concern should be tempered by the possibility of substantially lower spawning success of the farmed fish in the wild (Fleming et al. 2000, Fleming and Petersson 2001).

While there is presently no evidence of genetic impacts due to the escape of farmed Atlantic salmon, the taxonomic difference of this species from Pacific salmon indicates that we should expect a very low risk of this occurring. Assessment of Pacific salmon escapes will be much more difficult, if not impossible, without intensive studies of farmed and natural populations.

4.2.2 Ecological effects involve potential disruption of wild salmon productivity.

Escaped farmed salmon, whether Pacific or Atlantic species, compete with wild salmon for food, space and spawning habitat. Escaped salmon could disrupt wild salmon habitat and spawning behaviour. The alterations of habitat could include the digging up of wild females' redds and destruction of wild salmon eggs due to later spawning of escaped salmon (e.g., Atlantic salmon tend to spawn later than most Pacific salmon). In other instances, the farmed fish may spawn earlier and occupy spawning and rearing sites – the "prior residency" effect (e.g., Atlantic salmon tend to spawn before Steelhead trout). The magnitude of the effects will vary with size of the two populations, timing of spawning, specific characteristics of habitat and age and conditions of the two populations (Gross in Harvey and MacDuffee 2002, Volpe 2001b).

If Atlantic salmon are able to spawn successfully and the juveniles emerge earlier than wild salmonids, then the earlier-emerging Atlantic juveniles could establish their territories and compete with the wild fish. The fish that have established territory first will usually be more successful in securing food, space and cover. Thus, earlier-emerging Atlantics might displace local species (Volpe 2001b). Tompkins reported at the 2001 Ecological Interactions conference that her surveys revealed that while escaped Atlantic salmon shared the same food sources as Pacific salmon, the following kinds of information were still regarded as unknown: "migration patterns, timing of entrance and distribution into fresh water systems, spawning window, and overall impact on stream ecology." (Tompkins 2001)

The ecological effects of species interactions can vary depending on the abundance of each species. During periods of depressed production, such as is currently occurring in many southern B.C. steelhead populations, the ecological impacts of feral Atlantic salmon could increase if strong competition occurs (i.e., for preferred habitats). Alternatively, depressed abundance may simply allow for rearing of both species without serious impacts. The impacts of these interactions will depend on the productive capacity of the stream for each species, the relative abundance of the species and the sources of ecological competition between them. While many people may expect that colonization of Atlantic salmon would have negative effects on Pacific salmonids (Volpe et al. 2001), it remains possible that species could partition resources and co-exist without significant impacts on wild Pacific salmonids.

4.2.3 Escaped farm fish could transfer disease to fish in the wild.

The disease section (Chapter 3) has dealt with transmission of diseases from farmed fish in net pens to wild fish. There is also evidence that escapees can carry and horizontally transmit diseases and parasites to wild salmon. In 1999, wild Atlantic salmon in New Brunswick were found for the first time to have ISA, and escaped farmed salmon entering freshwater to spawn were found to carry it (see Section 3.4.1). The analysis of transmission by escapees is complicated by the fact that some diseases and parasites may be transmitted to wild salmon as they migrate through farming areas on their way to the ocean.

Norwegian researchers Johnsen and Jensen (1994) attempted to determine whether farmed escapees contributed to the spread of furunculosis in the Norwegian settings they examined. They concluded that the spread of the disease along the coast and into numerous Norwegian rivers was probably related to large escapes that had taken place at the same time.

Gross noted (in Harvey and MacDuffee 2002) that the interaction of genetic effects or vaccines with the escape issue could lead to risks to wild salmon. Disease- or parasite-resistant fish, while themselves healthy, might act as "Trojan horses" – transmitting pathogens to wild salmon that are not as well protected from the particular pathogen.

The risk of disease transfer from farmed fish to wild populations is difficult to quantify. The risk will be a function of the number of escapes (highly variable and unknown accuracy), the level of infection in the farmed population, and the susceptibility of the wild populations that the escaped fish may come in contact with (after accounting for the probability of survival of the escaped fish in the natural environments).

McVicar (1998b) provides a good summary of these issues based on experiences in the North Atlantic. This paper recognizes that as long as escapes occur and there are infectious agents in the farmed population, then it is inevitable that some of these escapes will carry infection and may transmit these infections to wild fish. The conclusions of that 1998 advisory document, however, place these concerns in perspective:

> "1) The movement of live fish and equipment between areas associated with fish farming activities carries the greatest risk of introducing new infectious agents and disease [i.e., non-endemic diseases] to an area. The main risks linked to live fish movements have been identified and are being controlled by legislation [in the North Atlantic countries]; several serious disease incidents in wild salmon populations have been directly associated with these.
>
> 2) Fish farms often carry elevated levels of locally endemic disease in their stocks which are likely to transfer to the wild with any escaped fish. No serious disease incidents have been shown in wild populations associated with the escape of such fish. However, there has been little research effort directed at this question."

With respect to risks associated with the transfer of disease via escaped farmed fish, and endemic diseases, the risks seem to be low but cannot be ignored. Currently, the numbers of potentially diseased, escaped salmon are so low relative to the numbers of wild salmon that the potential for disease transmission is also low. The same issue with non-endemic diseases would be of greater concern, but the risk of introduction of new pathogens appears to be low due to controls placed on the importation and/or movement of fish and eggs, etc. (see Section 3.5.1).

4.3 Points of view on specific escapes issues

4.3.1 Are escapes intentional as well as accidental?

Point of view: There are allegations of intentional releases of "under-performing" salmon.

It has been reported that "under-performers" (smaller, sometimes less healthy fish), perhaps as many as 1% of total stock, are released or allowed to escape into the wild, both in B.C. and Norway. Those who allege that this is taking place say that farmers can release or allow fish to escape without any realistic prospect of having to pay any penalty for doing so (Ecological Interactions 2001). Inadvertent releases could take place because some fish are small enough to swim through the net mesh.

Point of view: It is not in farmers' interest to release under-performers into the wild.

Industry spokespersons allege that, while intentional release of under-performers may have been a practice in the past, it is not being done now. Regulations and conditions of license, as well as industry codes of practice and operating practices of individual companies make intentional releases unlikely.

4.3.2 Does historic failure to successfully introduce Atlantics to B.C. rivers mean that present and future colonization is unlikely or impossible?

Point of view: History may not be a good guide to the present or the future in this case.

Conditions change through time in ways that may make it more likely that introductions will succeed and that invasion and colonization could successfully take place. Some wild salmon stocks are in weakened condition as a result of various environmental stressors and decreased population size. This makes it more likely that the "prior residency" theory will apply. This theory stresses the importance of seasonal factors, time of establishment, and relative numbers, ages and conditions of wild versus Atlantic salmon in a given location (Volpe 2001b).

Point of view: History and recent research suggest that the likelihood of colonization is low.

Some feel that changes have not been significant enough to suggest that successful introductions are more likely to take place now than in the past (Ginetz 2002). All deliberate attempts to establish runs of Atlantic salmon on the B.C. coast have failed. Fisheries and Oceans Canada (2000) summarizes the uniformly unsuccessful experience in the early years of the twentieth century, when "nearly 200 introductions (were) made into 52 different water bodies all over the coast of B.C., (with) a total of 13.9 million eggs, alevins, fry or smolts."

4.3.3 Are farmed Atlantic salmon able to survive in the wild?

Point of view: Atlantic salmon are not able to survive very well in most cases.

Atlantic Salmon Watch (2001) reports that stomachs of Atlantic salmon caught in B.C. are generally empty, suggesting that they adapt poorly to survival in the wild. A report by McKinnell et al. (1997) supports this supposition. Based on the limited number of adults observed in freshwater compared to the significant numbers of escapes, the survival of Atlantic salmon in the ocean seems to be poor.

Point of view: There is some evidence of the survival ability of Atlantic salmon.

In some instances, Atlantics have been recovered as far north in Alaska as the Bering Sea (Alaska Dept. Fish and Game 2001 and 2002). There is some evidence of adult Atlantic salmon returning to fresh water and of juvenile Atlantic salmon rearing in fresh water in B.C. (Atlantic Salmon Watch 2001). With better husbandry, farmed salmon may now be better conditioned to survive in the wild.

4.3.4 Will farm salmon reach rivers and successfully spawn there? Have they already?

Point of view: Spawning is possible, but only in limited instances.

The terms invasion (i.e., escaped salmon spawning in the wild) and colonization should not be equated. Colonization means the establishment of self-sustaining or "feral" runs (Tillapaugh 2001). The number of conditions that must be met for successful colonization in a given coastal river make colonization unlikely; e.g., "Success in a series of life history stages, and in sufficient numbers to perpetuate the stock on a continuing basis [is required]." (Ginetz 2002)

Escaped Atlantic farm salmon are technically capable of producing offspring in the wild, yet research in Norway reported that they have "significant competitive and reproductive disadvantages" (Fleming et al. 1996). Some recent B.C. research, reviewing extensive historic experience, has concluded that a self-sustaining population has not developed and is not likely to develop (Ginetz 2002).

Point of view: Spawning of Atlantic salmon has occurred and, over time, may meet with greater success.

The competitive disadvantages may not be as significant as some believe. Furthermore, the disadvantages might be reduced over time, from generation to generation, or in the case of fish which have more freshwater experience. "The likelihood of widespread colonization increases with each natural spawning event that occurs." (Volpe 2001a)

4.3.5 Do the results of monitoring efforts to date suggest that colonization by escaped Atlantic salmon is occurring?

Point of view: Presence of small numbers of escaped salmon dispersed over a ten-year time frame does not constitute colonization.

It is important to differentiate between invasion of adults and colonization. Atlantic salmon are known to escape pens and invade (enter) freshwater systems. Colonization, however, requires that adult Atlantic salmon spawn successfully, that juveniles rear and emigrate to the sea, and that mature adults return to their freshwater stream to reproduce again. This process would complete a life cycle for Atlantic salmon in the B.C. environment and would at least demonstrate short-term colonization.

The report of escaped fish in B.C. rivers represents the accumulated total of sightings over a period of at least ten years and lacks both the magnitude (in some cases as few as 1-2 fish) and the sustained current presence to constitute colonization (Ginetz 2002). In terms of reproductive potential, the presence of small numbers of juvenile feral Atlantics in three B.C. streams (Atlantic Salmon Watch 2002) also does not constitute colonization. It does not meet the test of sustained presence of large numbers over an extended period of time (Ginetz 2002).

Point of view: The widespread presence of even small numbers of escaped fish suggests the possibility of colonization.

The present monitoring research covers only 1% of the potential rearing habitat on Vancouver Island alone; more research might reveal greater numbers of escaped salmon, and the presence of juvenile feral Atlantics in more than three rivers (Volpe 2001a and c.) Surveys reported by the ASWP clearly indicate that some Atlantic salmon escapes survive and invade B.C. streams and rivers (see Table 2). To-date, these data report 1,085 adult Atlantic salmon in 80 B.C. rivers and streams since 1987 (ASWP began in 1991).

Table 2: Atlantic salmon recorded in principal B.C. survey streams, recorded by the Atlantic Salmon Watch Program (data as of November 2002)

These 17 streams are surveyed frequently. The remaining 63 streams are not surveyed annually. These data only account for Atlantic salmon observed during sample surveys.

Sampling Class and Streams:	Years sampled	Number of Adults Observed	# of Yrs.	Average # of Adults per year
"Index Streams":				
Adam/Eve River	1997-2002	52	6	8.7
Amor de Cosmos River	1997-2002	3	6	0.5
Tsitika River	1997-2002	33	6	5.5
Salmon River	1995-2002	235	8	29.4
WCVI* Stock Assessment Survey:				
Bedwell River	1993-2002	114	10	11.4
Megin River	1993-2002	12	10	1.2
Moyeha River	1993-2002	67	10	6.7
Ursus River	1993-2002	60	10	6.0
Tahsis River	1995-2002	18	8	2.3
Leiner River	1995-2002	22	8	2.8
Kaouk River	1995-2002	2	8	0.3
Gold River	1995-2002	6	8	0.8
Burman River	1995-2002	4	8	0.5
Zeballos River	1995-2002	115	8	14.4
Atlantic Salmon Hatcheries:				
Colonial/Cayhegle River	1990-2002	13	13	1.0
Kokish River	1991-2002	41	12	3.4
Salmon River *(above)*	1995-2002			
Stamp/Somass River	1994-2002	10	9	1.1

*WCVI: West Coast Vancouver Island

Source: Atlantic Salmon Watch 2002

The surveys in these 17 streams account for 807 of 1,085 adult Atlantic salmon observed to date. The remaining 278 adults were observed during ad hoc or opportunistic surveys in 63 other streams over 12 years of record-keeping. These ad hoc surveys indicate an expected incidence of Atlantic salmon of only 0.4 Atlantics per survey (i.e., one survey is represented by each stream/year), or 4 adult Atlantic salmon expected in every 10 surveys. It is noteworthy that the frequency of adult Atlantic salmon in the above table of consistently surveyed streams can be many times the 0.4 value. This result suggests that annual surveys and properly designed sampling programs may demonstrate a higher incidence of Atlantic salmon in B.C. streams than has been identified in the monitoring reports of the ASWP.

Beyond these records of adult Atlantic salmon in spawning streams, there are also observations of juvenile Atlantic salmon in various B.C. streams (Atlantic Salmon Watch 2002). To date, 366 juveniles have been reported in 11 streams since 1996. Many of these reports are associated with net-pen rearing of juveniles in lakes or with Atlantic salmon hatcheries. However, 3 systems in northeastern Vancouver Island (Tsitika, Adam, Amor de Cosmos rivers) have verified observations of Atlantic salmon juveniles that are likely feral fish in these natural rivers (Volpe et al. 2000a).

Gross, who has developed mathematical models of invasion probabilities, states that, based on the B.C. experience to date, the complete colonization cycle is a likely outcome (Gross in Gallaugher and Orr 2000). Experts summarizing the results of a 2000 workshop at Simon Fraser University noted that, for juvenile Atlantics in B.C., "the only untested part of the life cycle is the early saltwater stage." (Gallaugher and Orr 2000, p.2)

4.4 What can be done about escapes from netcage salmon farms?

4.4.1 Improved monitoring

Some argue that monitoring should remain limited or strategic to investigate most likely locations. They suggest that higher risk areas should be monitored more intensively. They see this as more useful and cost-effective than province-wide or other forms of wide area coverage (Ginetz 2002, Tillapaugh 2001). DFO's response to the Standing Senate Committee on Fisheries on this point was as follows: "The extensive funding required for comprehensive monitoring would divert investments otherwise available to restore habitat and protect wild stocks – activities with proven benefits." (Standing Senate Committee on Fisheries 2001c). Others maintain that more extensive research would reveal the presence of more escaped Atlantics in more B.C. rivers, thus establishing more evidence of the steps toward colonization (Volpe 2001a and c).

There is a need for a consistent and statistically designed sampling program. Ideally the findings of monitoring efforts from each year should guide the prioritization of effort for the following year, in the context of an overall plan and program.

4.4.2 *Fish identification measures*

Fish identification measures and techniques have been proposed but not yet adopted as aids to monitoring in B.C. These could involve affixing of coded wire tags to the fish, or thermal markers, or a DNA or genetic marker that would identify farm and year of origin of the fish. Tagging by size category could provide a method for studying leakage. Such marking systems could also provide needed information on biology, life cycle and life history patterns of escapes (Ecological Interactions 2001). Tagging of farm fish has recently been required as part of a consent decree in a Maine (U.S.) court action against the major salmon farming companies in that state (National Environmental Law Center 2002). Thermal marking is being considered in Washington State. In that state, escaped Atlantic salmon are reportedly classified for regulatory purposes as "pollutants." (Environmental Defense Fund 1997 and Ecological Interactions 2001).

4.4.3 *Prevention through management practices*

Industry and government representatives maintain that the primary focus should be on escape prevention rather than on such activities as monitoring and recapture of escapees. They point to the new provincial Escape Prevention Regulations (MAFF 2002c) and to the improvements said to have been made in cage technology and industry practices in recent years (BCSFA). They point to the economic motivation of the industry to minimize and if possible eliminate escapes for economic reasons. Critics of netcage salmon farming would support strong efforts towards prevention (with continued attention to monitoring), given the possibility that even an escape level that is a small percentage of total production can be significant, both at present levels of production and as production increases in the future.

Improved cage design, anchoring, net management, guidelines for vessel operation near farms and rapid response to escapes, as well as more frequent and comprehensive inspections are possible escape prevention strategies. Industry representatives state that all these measures are being taken, and that improvements are being made on an ongoing basis (Krause, pers. comm. 2002). Legislation and regulations set standards for cage technology and inspection in B.C. and elsewhere in the world (MAFF 2002a). See Appendix 2 for more information on regulations.

Corporate adoption of ISO 14001 environmental management standards offers one method of engaging in systematic upgrading of management practices. The use of independent audit of achievement of best practices provides an objective standard for continuous improvement (ISO 2002). At least one B.C. salmon farming company (Marine Harvest) has achieved ISO 14001 certification; others may follow suit.

It has been noted that as farms are sited in new areas that are more exposed to more extreme weather conditions, ongoing upgrading of technology and regulation will be required. Furthermore, correct specifications must be accompanied by appropriate inspection, preventive maintenance and replacement management regimes (Scottish Executive 2002).

New technologies for monitoring potential escapes should be employed where feasible. Some that have been mentioned in recent literature include Doppler radar systems, fiber-optic cable augmented nets, and improved use of cameras.

4.4.4 *Fish Inventory Measures*

Volpe makes the point that fish inventory in pens is roughly determined by average weights of a sample of fish, rather than by exact fish counts (Volpe 2001a). This starting error, which has been estimated as 3% (Ecological Interactions 2001), may then be compounded by leakage and unaccounted losses due to mortality or predation.

Improved fish inventory techniques could be combined with tagging, so that both the number of fish put in the nets and the number removed by any means, including escapes, could be determined (Ecological Interactions 2001).

4.4.5 *Area Management Strategies*

Risk could be managed to some degree by establishing areas clearly zoned or set aside for fish farms at a distance from and clearly separated from wild salmon, to minimize potential wild salmon/farmed salmon interaction. This approach is being utilized in Scotland and Norway, and might be achieved through siting regulations or policies in B.C.

4.4.6 *Triploidy*

Only females are now being reared on farms raising chinook salmon. Triploidy, the intentional induction of a chromosomal abnormality, can be induced in salmon to render the female sterile.

While triploidy deals with the genetic (inter-breeding) aspects of the escapes issue, it does not directly address the ecological or pathological aspects of the issue. Escaped fish might still disrupt wild salmon spawning habitat or compete with wild salmon for food or space. Triploid fish might attempt to mate with fertile wild fish, leading to infertile wild matings. They might still transmit diseases or parasites to wild salmon, even if breeding or vaccination kept them free from disease. As well, from the farmer's point of view, triploid fish have disadvantages as culture organisms. It is reported that they do not grow well, in some cases being 25-30% smaller in size at harvest, and that a large percentage of hybrids are deformed or have soft flesh.

Nevertheless, triploidy and other sterilization techniques could be used more widely, even though the approach deals with only one aspect of the escapes problem. They might be most applicable to chinook/coho escapes.

4.5 Gaps in our understanding of the impacts of escapes

Our present knowledge of escapes and their consequences is partial at best. The monitoring and reporting systems are limited in scope, opportunistic, and have, by their nature, a wide range of variability and accuracy. They take advantage of volunteer effort as it is available. But knowing the actual number of escapes is only the beginning of the analysis. It is even more difficult to know how well the escapees survive, spawn, compete with wild salmon for spawning habitat, interbreed or transmit disease and parasites. A 2001 meeting of B.C. and international scientists, researchers and industry personnel concluded that the real impacts of Atlantic salmon escapes are not foreseeable or predictable based on the present level of knowledge (Ecological Interactions 2001).

Ongoing surveillance of both escaped fish and wild fish is required for the purpose of quantifying impacts and assessing how they affect population fitness.

The attendees at the 2000 Speaking for the Salmon workshop in Vancouver – researchers from Canada, the US and Europe – identified as high priority research items: habitat displacement in freshwater among juveniles, competition between juveniles for food and space in freshwater, nest superimposition, disruption of breeding behaviour and hybridization (Gallaugher and Orr 2000).

It was noted at this same workshop that in-laboratory research should be supplemented by large-scale, ecosystem-based research, which would evaluate colonization potential and impacts of feral Atlantics in B.C. The attendees recommended: "Ideally, such an experiment would encompass as many as twenty streams each with a diverse community of native Pacific salmon and trout species. Ten of the streams would be randomly selected as experimental streams and be seeded with Atlantic salmon either once or on an ongoing basis while the remaining ten streams would be used as controls." The new B.C. Aquaculture Research and Development Program lists "escapes" as one of its five priority research areas (BCARD 2002).

The increasing importance of DNA research to further the understanding of genetic impacts has been remarked upon by some observers (Harvey and MacDuffee 2002, EVS 2000). Genomic identification techniques have only been successfully used in fishery analysis in the past ten years. However, there is seen to be promise in slowly and steadily assembling gene bank information that will help researchers understand genetic impacts of farmed salmon on wild salmon.

4.6 Assessing the risks to wild salmon posed by escapes

Research findings from B.C. and other salmon-producing nations suggest that escaped farmed fish pose risks in varying degrees to wild salmon and their habitat. Analysis of these risks is complicated by the lack of pertinent B.C. data and of programs for analyzing these risks in a comprehensive, long-term manner.

4.6.1 Summary of over-arching issues related to escapes

Differing risks between Atlantics and Pacifics

There have been a few recent attempts to categorize and rank the different levels and types of risk that flow from different escape scenarios. Gross (in Harvey and MacDuffee 2002) provided a ranking of concerns for wild salmon by category of impact and type of escapee – Atlantic or Pacific. He regarded the risks of genetic impacts on wild salmon as low for Atlantics and high for Pacifics. He ranked the risk of ecological impacts as medium in the case of Atlantics and high in the case of Pacifics. He ranked the risk of disease and parasite impacts as high for both. The attendees at the 2000 Speaking for the Salmon workshop in Vancouver concluded that, regarding possible interactions between Atlantic salmon (recently escaped or wild spawned) and Pacific salmon, the highest potential impacts on native stocks come from juvenile interactions, and in the form of ecological interactions. They agreed that if Atlantics were to successfully colonize and Pacifics decline in a given stream, risks would be greater. They also saw hybridization between Pacifics as having potentially high impact on wild salmon (Gallaugher and Orr 2000).

Genetic risks related to escapes

In theory, genetic impacts on wild salmon (via reduction of diversity and through interbreeding) could occur as a result of farmed salmon-wild salmon interaction. In B.C., the risk would be high from Pacific to Pacific interbreeding, and extremely low from Pacific-Atlantic interbreeding.

Overall, risk of genetic introgression (gene flow between populations which hybridize) between wild Pacific salmon stocks and domesticated farm fish of the same species is the most serious escape consequence.

Ecological risks related to escapes

Ecological risks to wild salmon from escaped salmon exist in theory. Atlantic and Pacific escapees are both capable of disrupting wild salmon habitat and spawning behaviour, and competing with wild salmon for food and space. Among the ecological risks, the most obvious would be that of escapees sharing the same spawning grounds with wild salmon, followed by interactions amongst juveniles if spawning is successful. While establishment of feral Atlantic salmon populations in B.C. could occur with minimal ecological impacts on wild salmon, it remains to be determined what the actual extent of these impacts would be. Salmonids other than Pacific salmon (i.e., steelhead and trout) could be more seriously impacted.

Disease risks related to escapes

The risk of disease from escapes is difficult to assess with accuracy. Currently, the numbers of potentially diseased, escaped salmon are so low relative to the numbers of wild salmon that the potential for disease transmission is likely also low. Disease transfer from escaped salmon appears to be a lesser risk than impacts of disease from farm fish residing in net pens.

While the risks associated with the transfer of endemic disease via escaped farmed fish appear to be low, they cannot be ignored. The issue of transfer of non-endemic diseases would be of greater concern, but the risk of introduction of new pathogens appears to be low due to controls placed on the importation and/or movement of fish and eggs, etc. (see Section 3.5.1).

4.6.2 Data limitations in the assessment of escapes

As mentioned above, beyond the theoretical level, the analysis of escape risks can only address Atlantic salmon. Escaped Pacific salmon cannot be identified at this time because without artificial markers or highly technical analysis they cannot be distinguished from wild salmon. Therefore, information on Pacific escapes and naturally spawning populations cannot be gathered. The inability to monitor escaped Pacific farmed salmon is one of the most significant limitations on our ability to assess the impacts of escapes on wild salmon.

The limitations of survey designs and resources severely restrict our assessment of risk even for Atlantic salmon in B.C.'s river systems. These limitations include:

- only a small proportion of streams in B.C. are surveyed;
- budgets for surveys are limited;
- quantitative survey designs are lacking;
- stream survey methodology leaves room for uncertainty (e.g., diver expertise, percentage of stream covered, visibility conditions and season, and survey effort per stream).

Of particular concern is the observation in Section 4.3.5 that in streams that are frequently surveyed, more Atlantic salmon are observed than in streams with less survey effort. Currently, differences in survey design between streams complicate the interpretation of the limited data that has been collected. Annual surveys and properly designed sampling programs could demonstrate a higher incidence of Atlantic salmon in B.C. streams. Presently, the survey and data limitations allow some people to interpret the current observations to indicate a lack of Atlantic impacts. Others view these limitations as simply an inadequate assessment of a potentially extensive impact.

4.6.3 Summary of specific issues related to escapes

Format of issue review

Specific issues regarding the potential impact of escaped farmed salmon as analysed in Section 4.3 are summarized below in the following format:

Issue:* *Re-statement of the question

⇓ *Risk viewpoint:* This is a summary of the point of view supporting a lower risk of impacts on wild salmon from salmon farming.

⇑ *Risk viewpoint:* This is a summary of the point of view supporting a higher risk of impacts on wild salmon from salmon farming.

Best estimate: This is a statement of the risk based on a consideration of the strengths and weaknesses of each argument.

The following "best estimates" of risks posed by escapes must be qualified by the limitations of surveys currently conducted for escaped Atlantic salmon and by the absence of surveys that record or sample for escaped Pacific salmon. See Section 4.6.2 for further discussion of the problem of data limitations.

***Issue:* Are escapes intentional as well as accidental?**

⇓ *Risk viewpoint:* It is not in farmers' interest to release under-performers into the wild.

⇑ *Risk viewpoint:* There are allegations of intentional releases of "under-performing" salmon.

Best estimate: This question remains unresolved at this time. Though industry escape prevention practices have improved in recent years, the true numbers of intentional releases are unknown and, at present levels of monitoring and reporting, they cannot be determined.

***Issue:* Does historic failure to successfully introduce Atlantics to B.C. rivers mean that present and future colonization is unlikely or impossible?**

⇓ *Risk viewpoint:* History and recent research suggest that the likelihood of colonization is low.

⇑ *Risk viewpoint:* History may not be a good guide to the present or the future in this case.

Best estimate: Observations to date show that colonization by Atlantic salmon in B.C. waters is unlikely, though not impossible. However, sampling has been so limited that conclusions cannot be reached with any certainty. If the industry expands and/or survival of escapes increases, then the chance of colonization will also likely increase.

***Issue:* Are farmed Atlantic salmon able to survive in the wild?**

⇓ *Risk viewpoint:* Atlantic salmon are not able to survive very well in most cases.

⇑ *Risk viewpoint:* There is some evidence of the survival ability of Atlantic salmon.

Best estimate: Generally, farmed Atlantic salmon survive poorly in the wild. However, the ability to assess survival is limited by the survey limitations noted above. In the future the more escaped Atlantic salmon might be expected to survive as fish culture techniques improve their health and strength.

***Issue:* Will farm salmon reach rivers and successfully spawn there? Have they already?**

⇓ *Risk viewpoint:* Spawning is possible, but only in limited instances.

⇑ *Risk viewpoint:* Spawning of Atlantic salmon has occurred and, over time, may meet with greater success.

Best estimate: Escaped Atlantic salmon have reached B.C. rivers and spawned there. (As noted above, this observation applies only to Atlantic salmon since the presence of escaped Pacific salmon cannot currently be detected.) Because survey efforts have been constrained, the reported numbers represent the minimum occurrence of escapes. Survey designs have not permitted extrapolation from samples to estimations of actual numbers of escaped fish.

***Issue:* Do the results of monitoring efforts to date suggest that colonization by escaped Atlantic salmon is occurring?**

⇓ *Risk viewpoint:* Presence of small numbers of escaped salmon dispersed over a ten-year time frame does not constitute colonization.

⇑ *Risk viewpoint:* The widespread presence of even small numbers of escaped fish suggests the possibility of colonization.

Best estimate: The small presence of juvenile feral Atlantic salmon in B.C. streams does not prove that colonization is taking place. However, this data, combined with the observations of spawning Atlantic salmon, does suggest that colonization may occur. Moreover, these observations again represent the minimum occurrence, with actual numbers being at an undetermined higher level.

4.6.4 Overview of risks posed by escapes

The greatest risk of long term effects of escapes would be Pacific farmed salmon escapes affecting wild Pacific species, via genetic, ecological and disease impacts. However, our inability to monitor escaped Pacific salmon in the wild precludes any assessment of the associated risks. Information on escaped Pacific salmon is completely lacking.

The analysis of the specific risks of escaped farmed salmon concludes that escaped Atlantic salmon have survived in the wild and spawned in B.C. rivers, and that they have the potential to colonize in B.C. rivers. The extent of these phenomena and their potential to expand in the future is highly uncertain due to data limitations.

The risks that escaped, spawning and/or colonizing salmon pose to wild salmon are in the form of genetic, ecological and disease impacts. At present, such risks exist in theory but there is little evidence of their occurrence. There are some occurrences of disease transfer, although infrequent, and given the ratio of escaped to wild fish, the risk in the long term is low. Comparatively, depending on the ecological conditions, ecological impacts of escaped Atlantic salmon on wild salmon may or may not be of concern, depending on the status of the stocks. Long term genetic risks to wild Pacific salmon due to escaped Atlantic salmon are virtually zero.

5 HABITAT IMPACTS

Habitat impacts of salmon aquaculture are of two kinds: impacts on the seabed and impacts on water quality. As a general rule, seabed impacts are more closely limited to the vicinity of the farm site. Water quality impacts may be more widely dispersed, e.g. through the disposal of blood water (untreated mixture of blood and fish debris from harvested or slaughtered fish). The use of lights at the farm site also changes water quality, in the broad sense. Habitat impacts may affect various forms of marine life as well as human life. Further, concerns have been expressed, in particular by First Nations, about the impacts of salmon farm wastes on such traditional food items as clams, ducks, crabs and seaweed. Others have expressed concerns about the aesthetic impact of salmon farms. Few of these issues, however, have impacts on wild salmon. In this report, only the issues of seabed impacts and water quality are considered.

Two recent reports provide detailed descriptions of seabed impacts and water quality issues related to salmon farms on the Pacific coast: Levings et al. (2002) and Nash (2001). They provide information that updates and expands upon material in the provincial Salmon Aquaculture Review (Environmental Assessment Office 1997). Readers are referred to these reports for more detailed information.

Because salmon farming impacts on the habitat are not among the areas of debate central to potential impacts on wild salmon, and because little information is available on them (see Section 5.3), this section is not organized around specific issues, as other sections of this report are. Here, rather than examining specific impact issues, key factors affecting the nature, severity and measurement of salmon farming impacts on habitat are examined. This is working from the assumption that the habitat of wild salmon includes the habitat affected by salmon farms, and therefore impacts on wild salmon are possible.

5.1 Seabed

Wastes generated by salmon farms consist largely of fish feces, urine and uneaten feed, plus various types of chemical residues from such sources as antibiotics and net cleaning chemicals, and marine organisms falling off the nets. They impact the area under the pens and areas adjacent to them. The wastes cause chemical changes in seabed sediments as they decompose, and can result in oxygen reduction, or sometimes complete oxygen depletion. They also change the chemistry of the area and may smother or otherwise alter the community of organisms resident there. A number of factors can influence the size and character of the seabed impacts. They include size of the farm operation, stocking density, feeding practices, duration of farm operation at the site in question, physical and oceanographic conditions, natural biota of the region, and the assimilative capacity of the environment (i.e., the substrate type – muds, sand and gravel, or cobble and rock).

5.1.1 Factors affecting seabed impact

The impact of waste from a farm site is determined by volume of fish being reared, feeding efficiency and farm practices, and the local environment beneath and adjacent to the farm (depth, substrates, currents, organisms, etc.). The extent of these impacts is site-specific.

Proximity to the farm site

For most sites, seabed impacts occur in close proximity to the farm, and effects diminish rapidly as distance from the site increases. In most cases, there are no effects once a distance of 30-225 meters from the pens has been reached (Brooks 2001 in BCSFA), and the vast majority of seabed impacts occur within 30m (Nash 2001). Nash (2001) concluded, "the most important rule in the management of risk [to the environment] is therefore the careful selection of the [farm] site."

Sedimentation rates

The rate of sedimentation is affected by oceanographic variables and farm practices. Some reliable information exists on natural sedimentation rates in B.C., but no measures of sedimentation rates under salmon farms are available in the literature. Some locations in these areas may have unique sedimentation conditions, as in the case of fjords carrying glacial melt water with high sediment load. And salmon net pens themselves may modify local currents in ways that increase localized sedimentation.

Feeding

Feeding efficiency is one factor that determines the impact of waste from a farm site. Feeding practices are steadily improving and will reduce waste accumulation per fish reared. Ratios of food weight per unit of fish weight gain have been significantly reduced in recent years (Naylor et al. 2000, Roth et al. 2002, Levings et al. 2002).

Recovery time

It is important to recognize that after fish are removed from a site, the seabed impacts (chemical and biological) will naturally decrease over time. The rate of recovery is again site-specific depending on the degree of impact, local currents, and the availability of organisms to recolonize. The review by Nash (2001) notes a number of studies of recovery or remediation times, including two in B.C. (Anderson 1996, Brooks 2000). Anderson (1996) observed recovery times that varied from several months at sites with low initial impact to two years for severely impacted sites. Brooks (2000) conducted a more extensive study and monitored recovery over two years at multiple sites. In these cases, chemical and biological recovery of the benthos occurred within weeks or months at some sites, but would take two to three years in others. In each case, though, recovery was occurring naturally with no intervention or mitigation.

Standards and techniques for measuring impacts

While the seabed is capable of recovery, the impact of salmon farming on the benthos and the rate of recovery will be related to the control of wastes from the farms during salmon rearing. The Province of B.C. has recently (on Sept. 12, 2002) released the Finfish Aquaculture Waste Control Regulation (MWLAP 2002a and 2002b). This regulation provides a "performance-based standard" that would limit and localize the impact of a salmon farm on the seabed. The standard is based on measurement of free sulphide concentration at a farm sampling site on a soft bottom at or beyond 30 meters from the farm margin, which "must not be statistically significantly greater than 6,000 micromolar."

The acceptance of a chemical measurement standard as a surrogate measure related to the degree of impact on the animal communities using the local sediments/seabed can be explained as follows. Assessment of infaunal communities (i.e., organisms living in the substrate or soft sea bottom) is recognized as the most direct and sensitive method for monitoring biological responses to organic loading from salmon farms and the associated chemical changes in the sediments. However, this method requires specialized training and is costly. Consequently, the International Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (1996) has recommended the use of physiochemical measures, which are rapid and inexpensive surrogate measures for assessing biological response. The use of sulphides as the physiochemical measure is based on work by Wildish et al. (1999) in mud seabeds of the Bay of Fundy. The application of these measures, however, requires that the sulphide levels be related to changes in the biological community of the seabed. For B.C., the relationship is discussed in Levings et al. (2002, Figure 2).

Levings et al. (2002) do not disagree with the basic utility of a physiochemical surrogate measure but do suggest the need to ground-truth values for B.C. environments, and note that the measure cannot be extrapolated from one type of substrate to another. For example, B.C. coastal environments are frequently a mix of sand and gravel, and/or cobble and larger rock. They also note that the use of a single parameter does not adequately address the subject of ecosystem functions. Concerning the question of whether chemical surrogates provide meaningful ecological information, they conclude (p.18):

> "The proposed standards appear to be insufficient to prevent loss of productive capacity on mud habitats within benthic ecosystems in the vicinity of finfish operations. Among the organisms included in toxicology studies, the majority show adverse effects within a few days' exposure to S [free sulphides] concentrations considerably lower than the 1,300 micromolar standard proposed by the B.C. draft aquaculture legislation [prior to the final regulation]. Data from Brooks' (2001) report indicate that a sediment S concentrations of approximately 1,000 micromolar may result in a 50% reduction in benthic macroinvertebrate diversity at sites in coastal B.C. (Bright 2001)."

In light of all these limitations of a "sulphide in mud" standard, Levings et al. (2002) recommend development of "A system that allows for the use of multiple indicators and allows discretionary use of a variety of sampling scales… ." They suggest use of such indicators as "toxicity, area of seabed affected, reduced sediment relief, biodiversity, sedimentation rates, recovery rates, sediment carbon, metals, dissolved oxygen and seabed respiration, assimilative capacity, sediment grain size and depth of organic sediment, and bacterial and algal biofilms." They also suggest that performance-based standards are not appropriate for dealing with the problem of seabed impacts, because that problem does not meet the conditions that are generally felt to be required for effective use of the technique, namely: (1) the problem has a narrow focus; (2) the response to system change is well understood by science; (3) effects are reversible; and, (4) there is a management response to a "trigger."

Other analysts have suggested that multiple additional pollutants, such as pesticide and antibiotic residues, and heavy metals such as copper and zinc, should also be measured and tracked, to provide a more accurate measure of the impacts of the farming operation. As well, they feel it is inappropriate to use sulphides as the indicator until there has been a determination of the varying background levels of sulphide that may exist at different locations in the B.C. marine environment (Langer 2002). Paone (2002) has pointed out that there may also be differing seasonal impacts on marine organisms that should be taken into account.

5.1.2 What can be done about seabed impacts?

Tracking pollutant levels and regulation

As noted above, the new B.C. Waste Management Act calls for tracking of sulphides as the primary pollutant indicator (MWLAP 2002a). The above discussion also explains potential weaknesses in this approach.

Siting

Farm siting practices can incorporate seabed conditions as part of siting criteria, recognizing the importance of site selection as a way of managing risk to the environment (Nash 2001). If farms are sited in deep water, away from salmon streams or shoreline clam beds or kelp beds, and over bottom conditions that support fewer organisms, impacts will be less. Mixing of currents and strong tidal currents are desired features.

Some waste impacts in B.C. are from sites established in earlier days of the industry which were not able to be fallowed during the seven-year moratorium period.

Fallowing of sites

Fallowing is temporary non-use of the site. It allows the seabed under the farm site to recover. The time required for recovery is highly variable, ranging between 5 and 50 months (Anderson 1996), depending on the level of impact and seabed conditions. Fallowing schedules should incorporate information on biological as well as chemical benthic impacts. If fallowing schedules are based solely on chemical factors, that practice could leave various biological communities at risk (Langer 2002).

Feeding techniques

The amount of waste feed that sinks to the seabed can be minimized through monitoring of feeding, use of underwater camera technologies, and feed application techniques that reduce sinking of uneaten feed. Changes in feed composition have also resulted in more digestible feed, with less waste generated (Krause, pers.comm. 2002).

Cumulative impacts

Levings et al. (2002) note that seabed impacts from salmon farming could be of greater concern if considered in the context of the cumulative impacts related to multiple industries. Analysts note that although forestry, fishing and aquaculture all have the ability to impact seabeds – through log storage, bottom trawling and farm waste generation – standards for assessing their combined impacts do not exist (Levings et al. 2002, Milewski 2001). These cumulative effects are uncertain but could amplify small impacts into larger.

5.2 Water quality

Salmon aquaculture operations may impact water quality in a number of different ways. These include algal blooms; antibiotic residues; blood water generated during harvesting or processing; impacts from net cleaning and in some cases from net disposal and composting; and mort (fish that have died prior to harvest) movement, storage and disposal. Some of these impacts, including a changed light regime, take place in the water column that is part of the farm. Other impacts take place in close proximity to the farms, under or adjacent to them. Still other impacts can take place at a distance from the farms, as fish are transported for disposal, or at and around processing plants. Some of these impacts are on water quality only; others are on both the benthos and the water.

5.2.1 Analysis of water quality issues

Nutrient loading and algal blooms

Salmon farm wastes may include dissolved components in the form of nitrogen and phosphorus. Nitrogen and phosphorus loading may initiate eutrophication (nutrient enrichment), which might alter the food chain structure in an area and lead to ecological simplification, as well as to algal blooms, hypoxia or anoxia, adverse effects on fishes and invertebrates, and changes in the structure of benthic communities (Milewski 2001). The magnitude of the effect, in any given case, will depend on such factors as volume and duration of the loading and the assimilative capacity of the receiving waters. Other sources of nutrient discharges may also be involved, in addition to fish farms.

Algal blooms (phytoplankton blooms) occur in nature. They may be more frequent with climate change and warming trends. It has also been suggested that salmon farms can increase the chances of blooms. Recent Scottish research noted that the number of toxic blooms had increased there in recent years. The report suggested that the increase might stem from a number of causes, salmon farming among them (Scottish Executive 2002, MacGarvin 2000). Waknitz et al. (2002) assert, "there is no measurable effect on phytoplankton production near salmon farms, even in countries with substantial development of salmon farms." Others say that increased frequency may make these blooms potentially harmful to finfish as well as shellfish (MacGarvin 2000).

A recent B.C. study noted that "Some algal species not normally toxic may become so when exposed to altered nutrient regimes from over-enrichment … Approximately 20 of the 5,000 known phytoplankton species along the west coast produce toxins or are directly lethal to fish." (G3 Consulting 2000) However, it is unlikely that wild salmon would be among the types of finfish affected – the high rate of movement of wild salmon – smolts or adults – probably prevents morbidity (Bakke and Harris 1998). The impacts of blooms beyond the farmed fish are probably greater on shellfish than on wild salmon. Although wild salmon have greater opportunity to avoid harmful blooms (Kent 1998), a potential impact on wild salmon is the depletion of oxygen in the water.

Antibiotic residues

Antibiotic residues can impact adjacent waters and organisms. They may be found in the water as well as on the ocean floor. Those opposed to salmon farming on environmental grounds believe that antibiotics are used excessively (CAAR 2002, Morton 1995). Conversely, a veterinarian commenting on the current usage of antibiotics in B.C. salmon farming said, "the use of antibiotics in salmon farming is very limited … . If antibiotics are used for salmon, it is usually just for a few days, once or twice in the life of the salmon, and they are used under the prescription of a licensed veterinarian." (Sheppard 2000) See Section 3.3.3 for discussion of antibiotics as a treatment for bacterial disease. There it is noted that usage has decreased substantially over the last decade.

In any case, antibiotics used at farm sites are not likely to affect migratory fish such as salmon since they are not in the vicinity of the farm long enough to absorb the antibiotics. As for other impacts of antibiotics on habitat, secondary effects on salmon are possible as a result of connections through the food chain.

Blood water

Blood water is part of the harvesting process. It is an untreated mixture of blood and fish debris from harvested or slaughtered fish. There is risk that blood water bearing disease might impact wild salmon. Blood water has very high biological oxygen demand (BOD), and can negatively impact dissolved oxygen levels in the water. It is reported that approximately 2/3 of the farms stun and bleed their fish at off-site processing facilities, where the process is subject to regulation of the processing facility and filtration usually takes place before water is returned to the marine environment. The remaining 1/3 stun and bleed at their sites and dispose of blood water there, or en route to the processing plants (MWLAP 2001 and 2002c).

Mort disposal

Mort disposal might pose risks to wild salmon in some instances. Morts (fish that have died prior to harvest) may be infected and release pathogens to the environment if they are not disposed of properly in one of the six authorized composting facilities on Vancouver Island. Mort storage, movement and disposal may be done by off-site treatment and disposal facilities, where the morts are composted, buried or incinerated. Some disposal may take the form of ocean disposal of fish or of shipment of dead or diseased fish for composting or to rendering plants distant from the producing area.

Disposal of IHN infected morts has been of particular concern: "… concern was expressed about the collection and disposal of morts (dead fish) from farms and fish processing effluent (blood, viscera) as potential sources of disease transference." (Standing Senate Committee on Fisheries 2001b, p.16) One example of mort and blood water disposal that ran the risk of infecting wild salmon is a 2002 Fraser River incident. In that case, at a time when juvenile sockeye were migrating through the lower Fraser River to the sea, a court injunction was obtained to stop off-loading of diseased morts at a lower Fraser River processing plant (David Suzuki Foundation newsletter, n.d.).

Net cleaning

Net cleaning takes place on land, floats or barges. Net cleaning chemicals (anti-foulants) contain copper. Disposal of these compounds can result in impacts from buildup of copper on the seabed as well as in the water column. The net cleaning is done in a way that releases "surges" or "bursts" of pollution, which may be more difficult for the environment to absorb than gradual releases. In some cases, the nets themselves are reportedly composted on the ocean floor, a practice that MWLAP has recommended cease. This practice could cause impact to the water column and the seabed (MWLAP 2001 and 2002c). Wastewater and debris generated through the net cleaning process can have a negative impact on oxygen levels in the marine environment and the benthic community (MWLAP 2002c).

5.2.2 What can be done about water quality impacts?

Algal blooms

Farmers can protect their stock from blooms by deploying material such as polyester tarp skirting around the pens and forcing upwelling of clean, deep water into the pens with pumped air.

Assuming that salmon farms contribute little to algal blooms, treatments used at the farm site are irrelevant to wild salmon.

Net cleaning practices

Net cleaning chemicals might be replaced in some cases by net drying practices – as are being used in Norway (Krause, pers. comm. 2002). MELP proposed, in 2000, the development of an action plan on net washing impacts, which would involve industry and DFO. The current status of this initiative was undetermined at the time of writing.

Antibiotic residues

The industry has replaced some antibiotic use with vaccines over the years. This, and continued careful control of dosage, are likely to reduce over time the impacts from their use beyond the animals to which they are administered.

Blood water and mort disposal

Appropriate management regulations can provide the means for effectively controlling and managing the impacts of blood water and mort disposal.

5.3 Gaps in our understanding of habitat impacts

The literature reviewed did not suggest other research priorities in the area of water quality impacts. Regarding algal blooms, there is a need for more research on whether and why blooms might be increasing in frequency, and the possible risks to wild salmon. The research should ideally expand the impact area for study, since there is some evidence that blooms may increase at a distance from farms, rather than adjacent to them (G3 Consulting 2000).

Regarding seabed impacts, while a great deal of monitoring and impact assessment data has been collected in recent years by B.C. government staff and consultants to industry, only limited analysis of that data and publication in peer-reviewed journals has taken place. Levings et al. (2002) qualified their presentation by emphasizing that they "found almost complete absence of peer reviewed (journal) papers in the literature from B.C." There appears to be essentially no information on concerns related to cumulative impacts from multiple industries affecting the seabed.

While this paucity of information is of concern for assessment of benthic impacts and impacts on other marine resources (such as shellfish and marine plants), as stated above the impact on wild salmon is likely very low.

Levings et al. (Appendix II, 2002) present some specific recommendations for further research, as follows:

- Investigate geochemical conditions (hypoxia, sulfides, redox, etc.) and organisms in the benthic boundary layer under and near fish farms.
- Determine effects of fish farm waste and sediment on incubating eggs of demersal and benthic fish.
- Document reversibility of loss of productive capacity owing to net pen operations.
- Develop methods for assessing cumulative effects of salmon net pen operations together with other seafloor disruptions such as wood waste and trawling.
- Develop tracers for far field effects.
- Continue development of assimilative capacity models.
- (Conduct) synoptic investigation of sedimentation rates in representative coastal areas.

- (Assess the) contribution of algal biofilms to productive capacity and the effects of bacterial biofilms on invertebrate production.
- Test the practicality of using a grid system to map sediments in a farm lease including habitats under pens.
- Investigate how changes in key invertebrate species can affect productive capacity.

Levings et al. (Appendix II, 2002) further suggest that there should be a multi-disciplinary scientific discussion to determine what parameters should be included in benthic analyses that are appropriate for the B.C. environment.

5.4 Assessing the risks of habitat impacts to wild salmon

5.4.1 Assessing the risks posed by seabed impacts

The literature on salmon farming frequently discusses possible negative impacts of salmon farm wastes on other fauna such as shellfish. The measurement of impacts on the seabed is controversial, due to concerns about the level of free sulphides set as the standard and the appropriateness of the use of performance-based standards in this application.

Despite recognition of environmental impacts of salmon farming on the seabed generally, there appear to be no scientific efforts to determine impacts to wild salmon. In theory, however, indirect effects on wild salmon related to changes in the food chain as well as cumulative effects are possible.

5.4.2 Assessing the risks posed by water quality impacts

Wild salmon could be negatively impacted if disposal of diseased morts or blood water coincides with their migration or spawning activity. This was one of the primary concerns of those who sought the court injunction against possible pollution of the Fraser River by disposal of fish farm morts and blood water in early 2002. However, at other times and places it is unlikely that diseases would be transmitted to wild fish from infected farmed morts or blood water.

Because wild salmon are migratory, they are unlikely to be exposed to antibiotic residues from salmon farms at levels that would be harmful. Similarly, the toxic effects of algal blooms are unlikely to affect wild salmon.

5.4.3 Overview of risks posed by habitat impacts

Habitat impacts, whether related to the seabed or to water quality, pose the lowest risks to wild salmon relative to escape-related or disease impacts. There are other potential risks beyond the scope of this research, such as those to biodiversity and human health, but the literature reviewed does not identify direct risks to wild salmon.

It is possible that there may be indirect risks to wild salmon via ecosystem effects or if the food chain becomes impacted as a result of the habitat impacts of salmon aquaculture. While this possibility is speculative at present, future impacts should not be discounted, and the employment of preventative measures does stand to benefit wild salmon.

6 CONCLUSIONS

The aim of this report is to expand and deepen the current public understanding about the potential impacts of salmon aquaculture on wild salmon by examining, evaluating and assessing the information and assumptions supporting the arguments of opposing interests. In pursuing this objective the report examined issues related to possible impacts of salmon farming on wild salmon, and reviewed available measures to reduce these impacts. A summary of the analysis of risks is provided here, along with a review of knowledge gaps related to the key issues investigated.

6.1 Risks posed by disease issues

6.1.1 Overview of risks posed by specific pathogens

Sea lice

Causality in the spread of sea lice from farmed fish to wild fish in British Columbia has not yet been proven to the highest standard of scientific scrutiny. However, the combination of scientific results from Europe (European Commission 2002, Scottish Executive 2002), preliminary studies of lice on juvenile salmon in B.C. and knowledge of sea lice-salmon dynamics presents a body of compelling evidence that sea lice from salmon farms do impact wild salmon. The main areas of uncertainty relate to how large or severe impacts will be, rather than to whether or not they will occur. McVicar, summarizing a 1996 ICES workshop on sea lice, concluded that "lice from salmon farms will contribute to lice populations in wild salmonids, but the extent and consequences of this have not been quantified." (McVicar 1997, p.1101)

Improvements in fish health management at the farms will reduce but not eliminate the potential for farms to transfer lice to wild salmon. Despite the natural prevalence of sea lice, wild salmon are vulnerable to them. In heavy infections, death results from erosion of the skin of the fish. Other possible consequences include premature return to spawning and reduced seawater growth. Indirect effects associated with disease transfer via lice could be an emerging issue of concern.

Sea lice are the most serious, immediate risk out of the three fish health issues considered in this report (parasites, bacteria and viruses).

Bacteria

Wild Pacific salmon are somewhat vulnerable to pathogenic infections from bacteria even though they generally are well adapted to the bacteria found in B.C.'s coastal waters. Concern over the potential for transfer of furunculosis from farmed to wild salmon is warranted despite the lack of direct evidence, but the effective use of vaccines substantially reduces the risk. Antibiotic resistance caused by the use of antibiotics on salmon farms does not appear to create risks to wild salmon. Bacteria pose the lowest risk to wild salmon, among the three fish health issues considered.

Viruses

The potential for farm sources of viral pathogens to increase infection of wild fish is reduced by the natural resistance of Pacific salmon to enzootic viruses. As well, the literature does not provide evidence of viruses that have caused problems at farms having negative effects on wild salmon. Nevertheless, migrating salmon could be exposed to viruses such as infectious hematopoietic necrosis (IHN) from farms at levels higher than those to which they are accustomed; and in other jurisdictions, infectious salmon anaemia (ISA) has been found to transfer from farms to wild fish. The risk that the exposure will be effective enough to cause infection increases when farm sites provide a reservoir for the virus, especially if diseased fish are not culled. Good husbandry and lower stocking densities on the farms can reduce the threat that salmon farms will act as reservoirs of viruses by making farm fish less vulnerable to infection; however, these efforts are currently limited by the lack of effective treatments for viruses. The level of risk posed to wild salmon by viruses of farm origin is intermediate to the higher risk from sea lice and the lower risk from bacteria.

6.1.2 Overview of risks posed by over-arching issues in the potential for disease transfer

Exotic diseases

The introduction of exotic diseases to B.C. through salmon farming could have severe – even irreversible – consequences for wild salmon stocks. Preventive measures have made the probability of this low; however the risk will never be zero. Global experience shows that the introduction of exotic pathogens through fish culture is infrequent, but when it happens it can have serious consequences. Of current international concern is the ISA virus. ISA has not been detected in B.C. although it has been introduced to New Brunswick and Maine. This virus appears to have been spread between regions through fish farming practices, though no significant impacts on wild salmon have been observed.

"New" diseases

The probability that new strains of disease will develop through salmon aquaculture (due to the use of antibiotics) and have negative impact on wild salmon appears to be low. The bacteria that are selected through antibiotics are not necessarily the hardiest representatives in a population and their numbers only become high due to the antibiotic treatment, for the period during which the antibiotic is applied. These *selected* are not newly created or mutated bacteria and they are not necessarily more virulent. However, the risk of a more virulent strain cannot be discounted. The impacts of this phenomenon, if it did occur, could be serious, although likely less catastrophic than the possible impacts of the introduction of an exotic pathogen. It is probable that previously undetected diseases that are native to this coast will be identified through outbreaks on salmon farms. The challenges will be to confirm that the pathogen does exist in wild stocks, and to ascertain the risks of biomagnification (increase through biological processes) of the pathogen in the farm context.

Health conditions on farms

In principle, if farms had no higher levels of pathogens than the surrounding marine environment then they would pose no incremental risk to wild salmon through disease transfer. High densities of fish in the net pens may increase susceptibility of farm fish to disease by increasing stress and will increase the probability of disease transfer among the fish in the net pen. Much progress has been made in health management in salmon farming: from vaccines through to containment of an outbreak, improved farming techniques have reduced the loss of fish to disease in salmon farms. Nevertheless, it is likely that concentrations of pathogens (most importantly, sea lice and viruses) are higher in the net pen setting than in the natural marine environment. As well, the recent IHN epidemic in B.C. demonstrated that infection can spread from farm to farm during a disease outbreak.

Exposure of wild fish to enzootic (indigenous) pathogens

It is true that fish in the wild do face disease risks, but evolutionary processes have led to a level of immunity in wild fish to the pathogens that surround them. The question is whether the presence of disease reservoirs in fish farms offers a significantly higher possibility of effective exposure of wild fish to infectious agents. In the case of sea lice, evidence is accumulating that it does. Chances of effective contact with pathogens are further enhanced by the siting of salmon farms on the migration routes of wild salmon. Another important variable in determining the risk of effective exposure is that of the survival time of pathogens that farmed fish may shed into the water column (which may then be carried by currents) or sediments below the net pens. In the case of lice and viruses such as ISA and IHN, survival time seems sufficient to pose a significant risk. In the case of bacteria such as furunculosis, the probability appears to be lower.

Evidence of disease transfer from farmed to wild fish

We know that farmed fish have diseases resulting from exposure to pathogens from wild fish. Since pathogen transfer is a two-way phenomenon, it is then possible for wild fish to have diseases resulting from exposure to pathogens from farm fish. While proof to the highest standards of scientific accuracy is lacking, circumstantial evidence, especially for sea lice transfer, continues to accumulate. Temporal and spatial associations between lice on farms and increases of sea lice on wild salmon are strong; our increasing understanding of the role of lice in fish health suggests that causal connections are possible. Alternative explanations for increased lice on wild salmon in the vicinity of salmon farms do not appear to be as plausible as the explanation of lice transfer from farms. The combination of scientific results from European research, studies of lice on juvenile salmon in B.C., and knowledge of sea lice-salmon dynamics presents compelling evidence that sea lice from salmon farms do impact wild salmon. In Europe, other examples of disease transfer include furunculosis and ISA.

6.2 Risks posed by escapes

6.2.1 *Data limitations in the assessment of escapes*

As mentioned above, beyond the theoretical level, the analysis of escape risks can only address Atlantic salmon. Escaped Pacific salmon cannot be identified at this time because without artificial markers or highly technical analysis they cannot be distinguished from wild salmon. Therefore, information on Pacific escapes and naturally spawning populations cannot be gathered. The inability to monitor escaped Pacific farmed salmon is one of the most significant limitations on our ability to assess the impacts of escapes on wild salmon.

The limitations of survey designs and resources severely restrict our assessment of risk even for Atlantic salmon in B.C.'s river systems. These limitations include:

- only a small proportion of streams in B.C. are surveyed;
- budgets for surveys are limited;
- quantitative survey designs are lacking;
- stream survey methodology leaves room for uncertainty (e.g., diver expertise, percentage of stream covered, visibility conditions and season, and survey effort per stream).

Of particular concern is the observation that in streams that are frequently surveyed, more Atlantic salmon are observed than in streams with less survey effort. Currently, differences in survey design between streams confound the interpretation of the limited data that has been collected. Annual surveys and properly designed sampling programs could demonstrate a higher incidence of Atlantic salmon in B.C. streams. Presently, the survey and data limitations allow some people to interpret the current observations to indicate a lack of Atlantic impacts. Others view these limitations as simply an inadequate assessment of a potentially extensive impact.

6.2.2 *Review of risks related to specific escapes issues*

Intentional escapes

The question whether escapes are intentional as well as accidental remains unresolved at this time. Though industry escape prevention practices have improved in recent years, the true numbers of intentional releases are unknown and, at present levels of monitoring and reporting, they cannot be determined.

Implications of historic failure to successfully introduce Atlantics

Observations to date show that colonization by Atlantic salmon in B.C. waters is unlikely, though not impossible. However, sampling has been so limited that conclusions cannot be reached with any certainty. If the industry expands and/or survival of escapes increases, then the chance of colonization will also likely increase.

Survival of Atlantic salmon in the wild

Generally, farmed Atlantic salmon survive poorly in the wild. However, the ability to assess survival is limited by the survey limitations noted above. In the future the more escaped Atlantic salmon might be expected to survive as fish culture techniques improve their health and strength.

Spawning of Atlantic salmon in the wild

Escaped Atlantic salmon have reached B.C. rivers and spawned there. This observation applies only to Atlantic salmon since the presence of escaped Pacific salmon cannot currently be detected. Because survey efforts have been constrained, the reported numbers represent the minimum occurrence of escapes. Survey designs have not permitted extrapolation from samples to estimations of actual numbers of escaped fish.

Colonization by escaped Atlantic salmon

The small presence of juvenile feral Atlantic salmon in B.C. streams does not prove that colonization is taking place. However, this data, combined with the observations of spawning Atlantic salmon, does suggest that colonization may occur. Moreover, these observations again represent the minimum occurrence, with actual numbers being at an undetermined higher level.

6.2.3 Review of risks posed by over-arching issues connected with escapes.

Differing risks between Atlantics and Pacifics

There have been a few recent attempts to categorize and rank the different levels and types of risk that flow from different escape scenarios. Gross (in Harvey and MacDuffee 2002) provided a ranking of concerns for wild salmon by category of impact and type of escapee – Atlantic or Pacific. He regarded the risks of genetic impacts on wild salmon as low for Atlantics and high for Pacifics. He ranked the risk of ecological impacts as medium in the case of Atlantics and high in the case of Pacifics. He ranked the risk of disease and parasite impacts as high for both. The attendees at the 2000 Speaking for the Salmon workshop in Vancouver concluded that, regarding possible interactions between Atlantic salmon (recently escaped or wild spawned) and Pacific salmon, the highest potential impacts on native stocks come from juvenile interactions, and in the form of ecological interactions. They agreed that if Atlantics were to successfully colonize and Pacifics decline in a given stream, risks would be greater. They also saw hybridization between Pacifics as having potentially high impact on wild salmon (Gallaugher and Orr 2000).

Genetic risks related to escapes

In theory, genetic impacts on wild salmon (via reduction of diversity and through interbreeding) could occur as a result of farmed salmon-wild salmon interaction. In B.C., the risk would be high from Pacific to Pacific interbreeding, and extremely low from Pacific-Atlantic interbreeding.

Overall, risk of genetic introgression (gene flow between populations which hybridize) between wild Pacific salmon stocks and domesticated farm fish of the same species is the most serious escape consequence.

Ecological risks related to escapes

Ecological risks to wild salmon from escaped salmon exist in theory. Atlantic and Pacific escapees are both capable of disrupting wild salmon habitat and spawning behaviour, and competing with wild salmon for food and space. Among the ecological risks, the most obvious would be that of escapees sharing the same spawning grounds with wild salmon, followed by interactions amongst juveniles if spawning is successful. While establishment of feral Atlantic salmon populations in B.C. could occur with minimal ecological impacts on wild salmon, it remains to be determined what the actual extent of these impacts would be. Salmonids other than Pacific salmon (i.e., steelhead and trout) could be more seriously impacted.

Disease risks related to escapes

The risk of disease from escapes is difficult to assess with accuracy. Currently, the numbers of potentially diseased, escaped salmon are so low relative to the numbers of wild salmon that the potential for disease transmission is likely also low. Disease transfer from escaped salmon appears to be a lesser risk than impacts of disease from farm fish residing in net pens.

While the risks associated with the transfer of endemic disease via escaped farmed fish appear to be low, they cannot be ignored. The issue of transfer of non-endemic diseases would be of greater concern, but the risk of introduction of new pathogens appears to be low due to controls placed on the importation and/or movement of fish and eggs, etc.

6.2.4 Overview of risks posed by escapes

The greatest risk of long term effects of escapes would be Pacific farmed salmon escapes affecting wild Pacific species, via genetic, ecological and disease impacts. However, our inability to monitor escaped Pacific salmon in the wild precludes any assessment of the associated risks. Information on escaped Pacific salmon is completely lacking.

The analysis of the specific risks of escaped farmed salmon concludes that escaped Atlantic salmon have survived in the wild and spawned in B.C. rivers, and that they have the potential to colonize in B.C. rivers. The extent of these phenomena and their potential to expand in the future is highly uncertain due to data limitations.

The risks that escaped, spawning and/or colonizing salmon pose to wild salmon are in the form of genetic, ecological and disease impacts. At present, such risks exist in theory but there is little evidence of their occurrence. There are some occurrences of disease transfer, although infrequent, and given the ratio of escaped to wild fish, the risk in the long term is low. Comparatively, depending on the ecological conditions, ecological impacts of escaped Atlantic salmon on wild salmon may or may not be of concern, depending on the status of the stocks. Long term genetic risks to wild Pacific salmon due to escaped Atlantic salmon are virtually zero.

6.3 Risks posed by habitat impacts

6.3.1 Assessing the risks posed by seabed impacts

The literature on salmon farming frequently discusses possible negative impacts of salmon farm wastes on other fauna such as shellfish. The measurement of impacts on the seabed is controversial, due to concerns about the level of free sulphides set as the standard and the appropriateness of the use of performance-based standards in this application.

Despite recognition of environmental impacts of salmon farming on the seabed generally, there appears to be no evidence of impacts on wild salmon. In theory, however, indirect effects on wild salmon related to changes in the food chain as well as cumulative effects are possible.

6.3.2 Assessing the risks posed by water quality impacts

Wild salmon could be negatively impacted if disposal of diseased morts or blood water coincides with their migration or spawning activity. This was one of the primary concerns of those who sought the court injunction against possible pollution of the Fraser River by disposal of fish farm morts and blood water in early 2002. However, at other times and places it is unlikely that diseases would be transmitted to wild fish from infected farmed morts or blood water.

Because wild salmon are migratory, they are unlikely to be exposed to antibiotic residues from salmon farms at levels that would be harmful. Similarly, the toxic effects of algal blooms are unlikely to affect wild salmon.

6.3.3 Overview of risks posed by habitat impacts

Habitat impacts, whether related to the seabed or to water quality, pose the lowest risks to wild salmon relative to escape-related or disease impacts. There are other potential risks beyond the scope of this research, such as those to biodiversity and human health, but the literature reviewed does not identify direct risks to wild salmon.

It is possible that there may be indirect risks to wild salmon via ecosystem effects or if the food chain becomes impacted as a result of the habitat impacts of salmon aquaculture. While this possibility is speculative at present, future impacts should not be discounted, and the employment of preventative measures does stand to benefit wild salmon.

6.4 Gaps in our understanding

Our understanding of the risks posed to wild salmon by salmon farming – through disease, escapes and habitat impacts – is plagued by unknowns and uncertainty. Our ability to assess risk is limited because we are dealing with partial, and in some cases a complete lack of data. Key gaps in our knowledge base and related research priorities are summarized here.

6.4.1 Knowledge gaps in disease issues and fish health

In 2000, the Auditor General found that there is a serious lack of information about the possibility of disease transfer from farmed to wild salmon populations (Desautels 2000). Last year, the Standing Senate Committee on Fisheries similarly recommended that the federal government invest more research resources to "determine the probability of disease and parasite transfer between cultured salmon and wild fish." (2001c, p.73)

Most studies related to disease and fish farming are about the pathogenicity of diseases affecting aquaculture. Few studies have focused on assessing the transfer of disease to wild salmon populations.

Two key challenges prevent definitive conclusions on a causal link in the transfer of infectious disease between farmed and wild salmon in B.C. First, we lack sufficient data on "natural" disease levels (including sea lice infections) in wild salmon. There is insufficient baseline data on the health of wild salmon, the stresses to which they are now subject, and the pathogens to which they are most susceptible. Second, because all of the diseases seen on salmon farms to date are also found in the wild it is difficult to distinguish natural occurrence of disease in wild populations from disease originating from salmon farms. These factors mean that it is difficult to determine the incremental mortality of wild salmon caused by disease from salmon farms.

Extensive research will be required to establish to the highest standards of scientific scrutiny the extent of the connection between disease in salmon farming and disease in wild salmon populations. Following is a sample of priority research needs:

- Monitor wild populations to investigate natural prevalence and range of diseases (including parasites) and to identify as yet unknown pathogens that exist in the wild.
- Establish the source of indigenous pathogens.
- Develop methods to detect changes in the level of disease in farmed and wild populations.
- Establish a structured disease surveillance program to determine relationships in the transmission of disease between farmed and wild salmon.
- Investigate the role of disease in early life cycle stages (fry and parr) and in the marine phase (especially regarding smolts).

6.4.2 Knowledge gaps related to escapes

Our present knowledge of escapes and their consequences is partial at best. The monitoring and reporting systems are limited in scope, opportunistic, and have, by their nature, a wide range of variability and accuracy. A 2001 meeting of B.C. and international scientists, researchers and industry personnel concluded that the real impacts of Atlantic salmon escapes are not foreseeable or predictable based on the present level of knowledge (Ecological Interactions 2001).

There is a need for a consistent and statistically designed sampling program. Ideally the findings of monitoring efforts from each year should guide the prioritization of effort for the following year, in the context of an overall plan and program. Ongoing surveillance of both escaped fish and wild fish is required for the purpose of quantifying impacts and assessing how they affect population fitness. High priority research topics include ecological interactions in freshwater habitats, relative reproductive fitness of escaped and wild salmonids, and identification of Pacific salmon escapees. Identification of Pacific salmon could be accomplished by marking programs. DNA research to further the understanding of genetic impacts has been remarked upon by some observers (Harvey and MacDuffee 2002, EVS 2000).

6.4.3 Knowledge gaps related to habitat impacts

Levings et al. (2002) state that there is little peer reviewed literature from B.C. related to seabed impacts. The authors caution against the extrapolation of data from other parts of the world to B.C. They suggest that there should be a multi-disciplinary scientific discussion to determine what parameters should be included in benthic analyses that are appropriate for the B.C. environment. There is a need to assess cumulative impacts of netpen operations together with other impacts on habitat since impacts on wild salmon may be mediated via ecosystem effects and related changes in the food chain.

6.5 Making sense of the salmon aquaculture debate

In this report we have provided a snapshot in time of what is currently known about farmed salmon-wild salmon interactions in B.C. and other jurisdictions whose experience may be pertinent. The topic is rife with uncertainties, and these will not be fully resolved even if current research priorities are met. Despite, or because of, these uncertainties, the information at hand points to many reasons for a cautious approach to netcage salmon aquaculture.

But the aim of this report was not to state definitive conclusions on risks posed to wild salmon by netcage salmon farming. Rather, the intention was to look behind the currently polarized and heated debate and examine the information and assumptions that support the arguments of opposing interests. It is hoped that the report will help observers of and participants in the debate to better judge the assertions of the various interests involved. Ideally, the report may also provide a vehicle for a more reasoned, collaborative approach to addressing some of the risks posed by salmon farming.

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Note that the two appendices have lists of references separate from those in this section.

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Note: Where available, the positions/associations of the authors are included in the reference. These affiliations were current at the time of publication but may not be current at the present time.

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7.2 Personal Communications

Interviews in person or by telephone were undertaken with the following individuals between July and October, 2002. When the interview was by telephone, this is noted in parentheses.

The following interviewees are cited in the text of the report.

Evelyn, Trevor P. T., Scientist Emeritus, Aquaculture Division, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, B.C. (telephone), 9 October 2002

Grydeland, Odd, President, BCSFA, Campbell River, B.C., 23 September 2002

Heard, Bill, Marine Salmon Interactions Program Manager, Auke Bay Laboratory, U.S. Fisheries Service, NOAA, Alaska, 30 October 2002 (telephone)

Krause, Vivian, Corporate Development Manager, Marine Harvest/Nutreco (with Andrew Forsythe, Hatchery Manager, Marine Harvest/Nutreco), Campbell River, B.C., 10 September 2002

McKinley, Scott, UBC Centre for Aquaculture and the Environment, West Vancouver, B.C., 27 Sept. 2002

Morton, Alexandra, Raincoast Research, Echo Bay, B.C. (telephone), 5 September 2002

Stephen, Craig, UBC Centre for Disease Control; Centre for Coastal Health, Nanaimo, B.C. (telephone), 5 September 2002

7.3 Interviews

Interviews in person or by telephone were undertaken with the following individuals between July and October, 2002. When the interview was by telephone, this is noted in parentheses.

The following interviewees are NOT cited in the text of the report.

Bastien, Yves, DFO, Commissioner for Aquaculture Development (OCAD), Ottawa, Ontario, 15 July 2002

Beamish, Richard, Senior Scientist, DFO Pacific Region, Nanaimo, B.C. (telephone), 18 September 2002

Brackett, Jim. Fish Health Veterinarian and Gen. Mgr., Syndel Laboratories, Vancouver, B.C. (telephone), 25 September 2002

Brooks, Dr. Kenn, Aquatic Environmental Services, Port Townsend, WA. (brief telephone discussion), September 2002

Ferguson, Andrew, Queen's University, Belfast, Northern Ireland (e-mail to David Peterson), October 2002

Hann, Jennifer, Biologist, Environmental and Lease Manager, Safety Supervisor, Heritage Salmon, Campbell River, B.C., 23 September 2002

Hicks, Brad, B. Hicks & Associates, Taplow Feeds, North Vancouver, B.C., 18 September 2002

Ginetz, Ron, BCSFA, Policy and Regulatory Affairs Advisor, Vancouver, B.C., 16 September 2002

Graham, Bud, ADM, MAFF; with Al Castledine, Director, Seafood Development, MAFF; and Al Martin, Director, Aquaculture Development, Sustainable Economic Development Branch, MAFF, Vancouver, B.C., 10 and 16 October 2002

Hunter, Lynn, David Suzuki Foundation, Vancouver, B.C., 17 September 2002

Jones, Simon, Research Scientist, DFO, PBS, Nanaimo, B.C. (telephone), 18 September 2002

Kent, Michael, Centre for Fish Health Research, Oregon State Univ., Corvallis, OR, North Vancouver, B.C., 24 September 2002

Lane, David, T. Buck Suzuki Foundation, North Vancouver, B.C., 24 September 2002

Langer, Otto, Director of Marine Conservation, David Suzuki Foundation, Vancouver, B.C., 1 and 15 August and 17 September 2002

Marliave, Jeff, Vancouver Aquarium and Pacific Fisheries Resource Conservation Council, Vancouver, B.C., various dates August-October (project advisor)

MacBride, Laurie, Georgia Strait Alliance, Nanaimo, B.C., 21 September 2002

McGreer, Eric, Sr. Aquaculture Biologist, Vancouver Island Region, MWLAP, B.C. (brief telephone discussion)

Millerd, Don, Batchelor Bay Management, North Vancouver, B.C., 16 September 2002

Morrison, Diane, Veterinarian, Marine Harvest/Nutreco, Campbell River and North Vancouver, B.C., 23 and 24 September 2002

Narcisse, Arnie, BCAFC, North Vancouver, B.C. (telephone), 20 September 2002

Nash, Dr. Colin, NOAA, Seattle, Washington (brief telephone discussion), August 2002

Orr, Craig, Watershed Watch, SFU, Vancouver, B.C. (telephone), 29 July 2002

Peterson, Anita, BCSFA, Campbell River, B.C. (brief telephone discussion), 23 September 2002

Piorkowski, Robert, Aquatic Ecologist, Invasive Species, Alaska Dept. Fish & Game, Juneau, AK (telephone), 20 September 2002

Riddell, Brian, Fisheries and Oceans Canada and Oceans and Pacific Fisheries Resource Conservation Council, Vancouver, B.C., various dates August-October (project advisor)

Rothenbush, Theresa, Marine Campaigner, Raincoast Conservation Society Sidney, B.C. (telephone)

Thomson, Andy, Atlantic Salmon Watch (brief telephone discussion)

Volpe, John, University of Alberta, Edmonton, AB (brief telephone discussions), various dates

Wadhams, Brian, Namgis First Nation, Alert Bay, B.C. (brief telephone discussion), 20 September 2002

Walling, Mary Ellen, Executive Director, BCSFA, Campbell River, B.C. (brief telephone discussion), 19 September 2002

Werring, John, Staff Scientist, Sierra Legal Defence Fund, Vancouver, B.C. (telephone), 18 September 2002

APPENDIX 1: THE PRECAUTIONARY PRINCIPLE

This appendix presents a series of definitions and elaborations of the precautionary principle and the precautionary approach. It illustrates the wide range of interpretations to which these concepts are subject.

UN Rio Declaration on Environment and Development

"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." (UN General Assembly 1992, Principle 15)

UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks

"… require[s] the avoidance of changes that are not potentially reversible; steps to identify and take measures without delay; and the priority to conserve the productive capacity of the resource where the likely impact on a resource is uncertain." (United Nations 1995)

FAO Code of Conduct for Responsible Fisheries

"… the absence of adequate scientific information should not be used to avoid taking conservation and management measures." (FAO 1995)

UN Convention on Biological Diversity

"Where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to minimize or avoid such a threat." (Convention on Biological Diversity, n.d.)

DFO Aquaculture Policy Framework (2002): "Aquaculture in the Context of the Precautionary Approach"

"Innovation offers tremendous opportunities to improve quality of life, but it is sometimes accompanied by scientific uncertainty and the potential for serious or irreversible harm. In these circumstances, governments are called upon to use the precautionary approach to manage risks while seizing the opportunities that innovation presents.

"The precautionary approach is a distinctive approach, within the realm of risk management, to managing risks of serious or irreversible harm where there is significant scientific uncertainty. It recognizes that lack of full scientific certainty shall not be used as a reason to postpone cost-effective measures to prevent environmental degradation. Canada recognizes that decisions are ultimately guided by judgement based on values and priorities.

"Canada's Oceans Act requires the government to promote the wide application of the precautionary approach to the conservation, management and exploitation of marine resources, in order to protect these resources and preserve the marine environment. Put simply, the Oceans Act defines the precautionary approach as erring on the side of caution.

"DFO's use of the precautionary approach in the context of aquaculture development will be informed by the Oceans Act and federal direction regarding risk management, including the application of the precautionary approach." (Fisheries and Oceans Canada (DFO). 2002a)

Canadian Environmental Protection Act (CEPA) (1999)

CEPA has adopted the 1992 Rio definition of precautionary principle in the preamble as follows: "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." (Department of Justice Canada 2002a)

Canada's Oceans Act (1997) and the DFO Oceans Strategy

As set out in the Oceans Act, the Oceans Strategy is based on the three principles of sustainable development, integrated management and the precautionary approach.

"The precautionary approach, defined in the Oceans Act as 'erring on the side of caution,' is a key principle to be applied in the management of ocean activities. Under the Strategy, the Government of Canada is re-affirming its commitment to promoting the wide application of the precautionary approach to the conservation, management and exploitation of marine resources in order to protect these resources and preserve the marine environment. Canada's Oceans Strategy will be governed by the ongoing policy work being undertaken by the Government of Canada." (Fisheries and Oceans Canada 2002b)

Government of Canada: Canadian Perspective (the Privy Council Office (PCO) Initiative)

In the year 2000, the Canadian government, through the Privy Council Office (PCO), began work on a federal initiative to discuss the application of the precautionary approach/principle in science-based regulatory programs (Government of Canada, Privy Council Office 2001). This initiative is in line with the Government's objective of strengthening risk management practices across the federal public service. The initiative prepared a discussion document on guiding principles for application of the precautionary approach and received public comment on it through the spring of 2002. A public report on these guiding principles may be published in the future.

The PCO work also includes setting the government reference point for the Federal Framework for Precautionary Approach / Precautionary Principle (PA/PP).

The PCO initiative is expected to define a comprehensive framework for the application of the PA/PP in government activities and including 15 departments/agencies. Once the Guidelines in the PCO "Proposed Federal Framework" become the official framework, there will be another level of work required regarding implementation and sharing of experience and interpretation among science-based departments.

The PCO's Performance Report for the period ending March 31, 2002 had the following comments and progress report on the initiatives dealing with the precautionary approach and principle (Privy Council Office: Performance Report for the Period Ending March 31, 2002):

"Regulatory Matters: Governments are increasingly called upon to adopt precautionary approaches to address new or emerging risks and to manage issues where there is a lack of scientific certainty. Beginning in November 2001, PCO, in collaboration with a number of other federal departments and agencies, consulted Canadians on proposed guiding principles for applying the Precautionary Approach/Principle to decision-making in Canadian public policy — a framework to describe the guiding principles inherent to practices and policies of the federal government. Ultimately, it would be a lens through which decision-makers and affected parties can assess whether the decision-making process is in keeping with the guiding principles and whether their decisions are in keeping with Canadians' social and economic values and priorities. Feedback was very constructive and supported a federal principles-based framework that applies the Precautionary Approach/Principle in a science-based, risk management context that will:

- Improve the predictability, credibility and consistency of Canadian public policy development that is adequate, reasonable and cost-effective;
- Support sound federal government decision-making, capitalizing on opportunities while minimizing crises and unnecessary controversies; and
- Increase Canada's ability to positively influence international standards and applications of the Precautionary Approach."

Auditor General's Report (2000)

"... [the Department of Fisheries and Oceans] will need to apply the precautionary approach by:

- applying new knowledge from ongoing research in the development of new regulations;
- monitoring and enforcing compliance with new regulations over the long term; and
- assessing the effectiveness of these regulations in protecting wild salmon stocks." (Desautels 2000)

NASCO Agreement on Adoption of a Precautionary Approach (adopted June 1998)

DFO has an obligation to conform to the precautionary approach under the North Atlantic Salmon Conservation Organization (NASCO) Agreement on Adoption of a Precautionary Approach (North Atlantic Salmon Conservation Organization (1998).

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Government of Canada, Privy Council Office (PCO). 2001. A Canadian Perspective on the Precautionary Approach/Principle Discussion Document. September 2001 http://www.pco-bcp.gc.ca/raoics-srdc/docs/precaution/Discussion/discussion_e.pdf

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United Nations General Assembly. 1992. Report of the United Nations Conference on Environment and Development (Rio de Janeiro, 3-14 June 1992) Annex I *Rio Declaration on Environment and Development*

APPENDIX 2: REGULATIONS PERTAINING TO SALMON AQUACULTURE IN B.C.

Introduction

This analysis of the regulatory environment for salmon aquaculture covers both the current situation and the identifiable changes that are foreseen from the provincial and federal governments. Although we describe current and pending laws and regulations, we do not comment on adequacy of the regulations or adequacy of enforcement efforts, as that is beyond the scope of this report. This appendix provides a summary description of each pertinent regulation. Detailed references and Web links are provided in the References section.

The regulatory environment for salmon farms includes federal and provincial laws and regulations. These governments share jurisdiction under a Memorandum of Agreement executed in 1988. Salmon farmers get their license to operate from the province, which has primary jurisdiction. The application has to be cleared with the federal government before it can be issued by the province. The primary federal regulatory actors are DFO and Environment Canada. Their regulatory responsibilities include enforcement of the provisions of the Fisheries Act, in particular Sections 35 and 36, the Navigable Waters Protection Act and the Canadian Environmental Assessment Act. The Canadian Food Inspection Agency (CFIA) and Health Canada have responsibilities in health-related matters and regulation of veterinary drugs and pesticides.

Much of the basic work on the structure of regulation of B.C. aquaculture was done as part of the Salmon Aquaculture Review (SAR). In particular, the summary tables in its Chapter 3 outline the federal/provincial framework of responsibility, much of which remains the same today (EAO 1997). The Discussion Paper on Management and Regulatory Framework for Salmon Aquaculture in B.C. provides a more detailed analysis of the regulatory structure as of 1997 – much though not all of which remains in place today (Hillyer 1997). MAFF provided a Status Report, in January 2002, on the progress that had been made to that date in implementing the recommendations of the SAR (MAFF 2002b).

Federal

Office of the Commissioner of Aquaculture Development

The Office of the Commissioner for Aquaculture Development (OCAD) advises DFO on overall policy direction (OCAD 2002). The Office was established in 1998. Its mandate has been recently extended to 2004.

OCAD has prepared an analysis of existing federal and provincial regulations pertaining to aquaculture (OCAD 2001). The Office also commissioned a companion report on the costs of these regulations to the industry (CCG Consulting Group 2000).

Fisheries and Oceans Canada (DFO)

DFO has primary federal responsibility for aquaculture. This responsibility is exercised through a number of different pieces of legislation and offices. DFO has recently (2002) issued an Aquaculture Policy Framework report (Fisheries and Oceans Canada (DFO) 2002a). The department is also preparing an Aquaculture Action Plan (DFO 2002a, Burgham 2001).

DFO screens aquaculture site applications for compliance with the Fisheries Act and the Navigable Waters Protection Act, and in carrying out its mandate sometimes triggers the Canadian Environmental Assessment Act (see below for details on each).

Office of Sustainable Aquaculture

Within DFO, the Office of Sustainable Aquaculture (OSA) is responsible for coordinating actions of other federal agencies that deal with aquaculture. The office was established in 2000. The head of OSA co-chairs the Canadian Council of Fisheries and Aquaculture Ministers (CCFAM) (see below).

Fisheries Act

The federal Fisheries Act prohibits harm to fish habitat (Section 35) and deposition of any deleterious substance in waters frequented by fish (Section 36).

Section 35(1): "No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat." This section is sometimes referred to as the "HADD" section. Protection of spawning grounds is encompassed under this section. Fish habitat is defined as "spawning grounds and nursery, rearing food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes." All fish habitat both used directly and indirectly by fish is encompassed under this section.

Section 35(2): an authorization under this section triggers CEAA.

Section 36(3): "no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter any such water." This section is sometimes referred to as the "pollution prevention" provision. DFO is the responsible agency, but by agreement, the program is administered by Environment Canada. Minister Thibault noted, "DFO, in partnership with Environment Canada, is currently studying the scope, content and desirability of Section 36 regulations for aquaculture." (Standing Senate Committee on Fisheries 2001c)

Navigable Waters Protection Act

The provisions of this act relate to ensuring safe navigation. When there is a requirement to issue a navigable waters permit the CEAA is triggered. Aquaculture installations are among the types of installations covered by the Act (Dept. of Justice Canada 2002c). DFO has responsibility for applying the act to aquaculture projects, and has issued an Application Guide in that regard (Fisheries and Oceans Canada, .n.d.).

Fish Health Protection Regulations

DFO's fish health regulations deal with movement of salmonid eggs and live salmonids between provinces and into Canada, to minimize introduction of diseases named in the regulations.

Fish Habitat Management Policy

This policy and guidelines pertaining to it are outlined by Fisheries and Oceans Canada (2002b). Information on guidelines for determination of HADD and for applying CEAA in the case of fish habitat issues is also provided.

Wild Salmon Policy

DFO's Wild Salmon Policy remains in draft form at the time of writing. There are currently four working groups working on implementation alternatives, one of which is the Aquaculture Working Group (Allison Webb, pers. comm. 2002).

Interim Guidelines for Salmon Aquaculture

DFO issued a large number of interim guidelines dealing with salmon aquaculture in the past year. The current status of these is unclear; they cannot be found on the DFO Web site.

Oceans Act and Oceans Strategy

DFO has lead responsibility for implementing the federal Oceans Act and Oceans Strategy. It is not clear whether provisions of the Oceans Act conflict with other existing federal law, such as the Fisheries Act, in the case of aquaculture.

Canadian Environmental Assessment Act (CEAA)

The Canadian Environmental Assessment Act (CEAA) specifies various regulatory acts/sections of acts (CEAA's Law List) that trigger the need for an environmental assessment. DFO is the primary law list trigger of CEAA for aquaculture. The DFO triggers relate to the need for an NWPA permit or Section 35(2) Fisheries Act (HADD) authorization. Environment Canada triggers CEAA when ocean dumping is involved. See below (Harmonized Guidelines and Regulations) for details on DFO's and Environment Canada's recent preparation of draft guidelines for conducting environmental assessments and CEAA screenings.

In the case of aquaculture projects, environmental assessments consider not only the effects of the project on the environment, but also the impacts of the environment on the project – including such factors as temperature, waves, currents and ice. Assessments consider the impacts on all federal resources – not just those that triggered the CEAA.

Canadian Environmental Protection Act (CEPA)

Environment Canada has responsibility for ocean dumping permits under emergency provisions of the Canadian Environmental Protection Act. (Dept. of Justice Canada 2002a.) In non-emergency disposal at sea situations, an environmental assessment of the proposed disposal would be required before a CEPA permit could be issued.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC)

This committee is responsible for identifying species that are endangered or at risk. This could include species of wild salmon. When the Species at Risk Act (SARA) becomes law, COSEWIC's listings will provide the basis for actions, such as recovery plans or strategies, that might be called for by the terms of the Act. The Act is not yet enacted at this time (November 2002).

Health Canada

Health Canada has jurisdiction over some aspects of fish health. It approves the use of veterinary drugs (Bureau of Veterinary Drugs) and regulates pesticides (Pest Control Products Act).

Canadian Food Inspection Agency

CFIA has jurisdiction over fish health inspection practices at fish processing facilities. It also administers the Feeds Act, the Health of Animals Act, and the Fish Inspection Act and associated regulations. It approves vaccines used on salmon farms.

Proposed National Aquatic Animal Health Program

The proposed National Aquatic Animal Health Program (NAAHP) is intended to fill some of the gaps that are now felt to exist in fish health regulation at the federal level. The Plan has been developed by representatives of the federal and provincial governments and the Canadian Aquaculture Industry Alliance (Canadian Aquaculture Industry Alliance 2002).

DFO has consulted with the province on disease surveillance and control programs for wild fish, which might become part of the NAAHP (MAFF 2002b).

Federal-Provincial Harmonization

Memorandum of Agreement

The province and the federal government have defined their respective responsibilities for aquaculture in a 1988 memorandum. For British Columbia, DFO is the lead federal agency and MAFF is the lead provincial agency.

Minister Thibault described the general intent of the federal/provincial aquaculture memoranda as follows: "They enunciate the federal government's aquaculture responsibilities, being scientific research, fish health and inspection, and protection of fish and fish habitat. The provinces' responsibilities include promotion, development and regulation." (Standing Senate Committee on Fisheries 2001a)

Harmonized Guidelines and Regulations

Harmonization between federal and provincial regulations to create a clear "one-stop shopping" application process is now underway. Both DFO and Environment Canada have recently prepared draft guidelines for conducting environmental assessments of finfish aquaculture projects (Fisheries and Oceans Canada 2002d; Fisheries and Oceans Canada 2002c). The latter document contains information requirements for CEAA screenings. Environment Canada has prepared guidance material on the same subject matter (Environment Canada 2001). The provincial effort at harmonization takes the form of the draft aquaculture application guidebook materials, which are being prepared at the time of this writing (reviewed but not cited, at MAFF's request). See also MAFF (2002d).

Canadian Council of Fisheries and Aquaculture Ministers

The Aquaculture Task Group of the Canadian Council of Fisheries and Aquaculture Ministers (CCFAM) works with the federal Office of Sustainable Aquaculture within DFO as a policy and program development team that works on a variety of projects (CCFAM 2002).

Federal/Provincial Fish Introductions and Transfers

Fish introductions and transfers are governed by regulations administered by the Federal/Provincial Introductions and Transfers Committee (Fisheries and Oceans Canada n.d.).

Inter-Agency Directors Aquaculture Committee

An Inter-agency Directors Aquaculture Committee was formed in October 2001 to coordinate aquaculture program and policy development. Member agencies include MAFF, MSRM, Land and Water B.C., MWLAP and DFO. This committee is developing a regulatory framework for managing aquaculture in B.C. (MAFF 2002b).

Provincial

Three ministries – Agriculture, Food and Fisheries (MAFF); Water Land and Air Protection (MWLAP); and Sustainable Resource Management (MSRM) – and one Crown Corporation – Land and Water B.C., (formerly B.C. Assets and Land) -are most directly involved in salmon aquaculture regulation. MAFF is the provincial lead agency. In line with overall provincial policy, it is expected that provincial regulation related to aquaculture will become increasingly performance-based in the future. For a discussion of overall policy, see Graham (2001). At least one other Ministry, Ministry of Health, is involved with the fish health aspects.

The province administers day-to-day operational responsibilities, and is responsible for licensing, monitoring and management of sites once they are approved and operational.

Ministry of Agriculture, Food and Fisheries

Fisheries Act

The governing provincial legislation is the Fisheries Act (RSBC 1996, Chapter 149). It authorizes MAFF to license operations and regulate on-site farming activities. It gives MAFF the authority to establish licensing requirements for farms (MAFF 2002a).

Aquaculture Regulation

The Aquaculture Regulation is issued under the provincial Fisheries Act. It governs the operational aspects of salmon farms. The recently revised Aquaculture Regulation was last amended in April 2002 (MAFF 2002a).

Escape Prevention Initiative

The newly-enacted provincial Escape Prevention Initiative is part of the Aquaculture Regulation (MAFF 2002e).

Net Strength Regulations

MAFF has recently issued upgraded net strength standards (MAFF 2002g).

Fish Health Regulations

Provincial fish health regulations are issued by MAFF. The regulatory and management regime is described on the agency's Fish Health Web page (MAFF 2002f).

Provincial IHN regulations require that farms suspecting a risk of IHN must immediately isolate their stocks and notify neighbouring farms. Disinfection can then be imposed (Nanaimo Daily News 2/16/02).

Marine Finfish Application Guide

Farm siting and relocation regulations are currently being developed. The responsibilities of the provincial government – MAFF and MSRM, and Land and Water B.C. are spelled out in a number of related documents (MAFF 2002c and 2002d, MSRM 2002 and Land and Water B.C. 2002a and b).

The goal is for each application/management plan to be to be approved within 140 days. Referrals are to be made to federal, provincial and local agencies within this time. Public comment and response and local open houses are also scheduled to be held during this time period.

Ministry of Water Land and Air Protection

MWLAP is responsible for regulation and monitoring of environmental aspects of salmon farming. MWLAP is responsible for ensuring protection of the marine environment and fish and wildlife species. This includes enforcement of the Waste Management Act, the Water Act, the Pesticide Act and the Fisheries Act as it relates to fish habitat.

"The Ministry's mandate extends to assessing impacts to fish and wildlife as the result of waste discharges, such as fish faeces, feed, sewage and blood water. The mandate also encompasses regulating the disposal of sewage, fish mortalities (morts), blood water, refuse and other wastes, the storage of hazardous materials, licensing and use of firearms." (MWLAP 2002c)

Finfish Waste Management Regulation

The new Finfish Waste Management Regulation was issued in September 2002 under the B.C. Waste Management Act (MWLAP 2002). All of the Waste Management Act, not merely the aquaculture provisions, is now undergoing an 18-month review. This was also announced in September 2002 (MWLAP 2002b).

Ministry of Sustainable Resource Management

Aquaculture Opportunity Studies

MSRM is responsible for the preparation of Aquaculture Opportunity Studies, which identify appropriate areas for aquaculture by region or sub-region (MSRM 2002).

Land Resource Management Plans

In its preparation of Land Resource Management Plans (LRMPs), the Ministry receives input on aquaculture-related issues from MAFF, MWLAP and Land and Water B.C.

Land and Water B.C.

Aquaculture Tenures

The Crown Corporation Land and Water B.C. has responsibility for processing applications for aquaculture tenures (Land and Water B.C 2002a). The procedures for assessing aboriginal interest in tenures are spelled out at (Land and Water B.C. 2002b).

Ministry of Health

The provincial Ministry of Health may in the future deal with fish health issues through the Animal Disease Control Act. As of January 2002, the Act had not been amended to deal with fish health issues (MAFF 2002b).

Regional Districts

At least one regional district – Comox-Strathcona – elects to zone a portion of its foreshore area. Where a regional district has thus exercised its zoning powers, its approval is required for sites in its area of jurisdiction.

However, it appears that the provincial government may, by Order in Council, seek to reduce this regional district authority by "treating oceans as farms" – lumping areas of foreshore water into the Agricultural Land Reserve (ALR), amending the Right to Farm Act to augment provisions that would protect aquaculture operations. This alternative is being studied by a task force which includes local and provincial representatives (van Dongen 2002). It could insulate salmon farmers from nuisance litigation if they were found by the Farm Practices Board to be using best farming practices and techniques.

References for Appendix 2: Regulations Pertaining to Salmon Aquaculture in B.C.

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GLOSSARY

Adaptability:	The capability of an organism to adapt to changing or future environmental conditions, the capability depends on adequate genetic variation remaining in the population.
Adaptation:	A genetically determined trait that increases the relative fitness of an individual in its environment (an adaptation refers to a current trait and results from the integration of past genetic and environmental interactions).
Age-class:	The brood year (year the fish was born) or the salt-water entry year that defines a cohort of fish (same as year class).
Blood water	An untreated mixture of blood and fish debris from harvested or slaughtered fish.
Biomagnification:	The increase of organisms through biological processes.
Causative (etiological) agent:	The cause of a clinically diagnosed disease, which sometimes has the same name as the disease itself.
Chemotherapeutants:	Chemical compounds used to treat and control diseases (e.g. antibiotics, pesticides).
(Fish) culture:	Cultivation of fish from broodstock. In salmonid enhancement and ocean ranching, the fish are released from the hatchery. In salmon farming, the fish remain in captivity through their whole life cycle.
Disease:	A condition of the body, or some part or organ of the body, in which its functions are disturbed or deranged. In fish, indicated by discoloration, mortality, behavioural changes (fish do not swim, or remain near surface), poor growth, changes in the quality of the flesh.
Enzootic:	Disease endemic to a particular region – naturally occurring, indigenous.
Epizootic:	Disease temporarily present in a population of animals, attacking many animals in a population simultaneously (like epidemic) – also called an "outbreak."
Etiology:	The study of the cause of a disease.
Evolutionarily significant unit:	A set of populations that is morphologically and genetically distinct from other similar populations, or a set of populations with a distinct evolutionary history.
Fallowing:	The process of leaving an aquaculture site unused for a period of time, in order to facilitate seabed recovery and rehabilitation (cf. abandonment).
Feral:	Animals belonging to or forming a wild population ultimately descended from individuals which escaped from captivity or domestication.
Fitness:	The relative ability of a genotype (an individual) in its environment to successfully contribute offspring to the next generation. In salmon,

fitness is frequently equated to the number of progeny produced per spawn.

Founder Effect: In genetic terms, the creation of a new population based on a very small number of parents. These "founders" may be a very limited portion of the genetic material in the source population. A "founder" event may have a similar effect but is caused within a population by a severe crash in population size.

Hybrid vigor: An increase in the fitness in a population due to the masking of recessive deleterious genes due to the mating of unrelated animals, usually from different populations.

Immunocompetent: A state in an organism describing its ability to mount an immune response.

Inbreeding depression: A loss of fitness in a population due to increasing relatedness of individuals within the population, and through the expression of deleterious recessive genes due to mating of related individuals.

Inbreeding: The mating together of individuals that are related to each other by ancestry; increased levels of inbreeding results in a loss of genetic variation within the population.

Introgression: Gene flow between populations that hybridize, i.e., the introduction of genes from a non-local population via the inter-mating of the two populations. The extent of gene flow depends on hybridization effects. Enhanced productivity may increase the rate of exchange (e.g. hybrid vigor), but reduced productivity over time (e.g. outbreeding depression) would reduce it.

Life stage: For wild salmon the life stages are: *alevins* emerge from eggs and reside in the gravel, *fry* emerge from the gravel and reside in freshwater or migrate to the sea, *parr* (pre-smolt) reside and grow in freshwater, *smolts* are a transition phase from freshwater parr to seaward migrants, *adults* live at sea until migrating back to their natal streams to spawn. The period of these stages differs between salmon species. (Stages from fry to smolt also known as juveniles).

Morbidity: The prevalence and severity of impacts of disease.

Morts: … or mortalities: deaths, specifically, farmed fish that have died prior to harvest.

Outbreeding depression: The loss of fitness in a population due to "swamping" the locally adapted genes by straying from a different population, and/or the breakdown of biochemical or physiological capabilities due to the mixing of populations with different genetic backgrounds.

Pathogen: Agent of disease/infectious agent. Those of concern here are viruses, bacteria and parasites. While the term is often used to include only the first two of these, usage in this report includes parasites.

Pathogenicity:	Whether or not the normal functioning of the fish is affected and the chances of survival of the fish are reduced; the ability to cause a disease.
Plasmid:	A linear or circular molecule of DNA which can replicate independently from the chromosomal DNA of an organism. If a proportion of DNA is added to that of a plasmid, the sequence can be added to a cell where it can replicate and alter the host genome.
Population:	Group of individuals of one species occupying a defined area and sharing a common gene pool. For wild salmon, a localized spawning group of fish that is largely isolated from other such groups.
Practical recovery time or "PRT":	The interval from cessation of aquaculture operations to the time when diversity cannot be distinguished reliably from the reference value.
Run/stock:	Genetically similar group of fish having a shared source and destination place or time. In the wild, the group of fish that return to the same geographic area (natal watershed), or that return at the same time period. On a salmon farm, the group of fish at a farm site.
Salmonid:	A category of fish that includes salmon, steelhead and trout.
Smolt/Smoltification:	Life stage/process that is the transition from freshwater parr to seaward migrants.
Stress:	A response to a situation that is beyond the scope of what the animal normally encounters, although stressors may be frequent and numerous. Health may be looked at as the capacity to deal with stress without succumbing to disease.
Virulence:	The ability of a microorganism to cause disease.
Year class:	The brood year (year the fish was born) or the salt-water entry year that defines a cohort of fish.

ABBREVIATIONS USED IN THIS REPORT

ALR	Agricultural Land Reserve (Province of B.C.)
ASWP	Atlantic Salmon Watch Program
BCAFC	B.C. Aboriginal Fisheries Commission
BCARD	B.C. Aquaculture Research and Development Program
BCSFA	B.C. Salmon Farmers Association
BKD	Bacterial kidney disease
BOD	Biological oxygen demand
CAAR	Coastal Alliance for Aquaculture Reform
CAIA	Canadian Aquaculture Industry Alliance
CCFAM	Canadian Council of Fisheries and Aquaculture Ministers
CEAA	Canadian Environmental Assessment Act or Canadian Environmental Assessment Agency
CEPA	Canadian Environmental Protection Act
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CSAS	Canadian Science Advisory Secretariat
DFO	Fisheries and Oceans Canada
DSF	David Suzuki Foundation
EAO	B.C. Environmental Assessment Office (no longer in existence)
EDF	Environmental Defense Fund
FAO	Food and Agriculture Organization (U.N.)
GSA	Georgia Strait Alliance
HADD	Harmful alteration, disruption or destruction (from federal Fisheries Act, s.35)
ICES	International Council for the Exploration of the Sea
IHN	Infectious Hematopoietic Necrosis
IHNV	Infectious Hematopoietic Necrosis Virus
ISA	Infectious Salmon Anemia
ISO	International Organization for Standardization
KTFC	Kwakiutl Territorial Fisheries Commission
MAFF	B.C. Ministry of Agriculture, Food and Fisheries
MELP	B.C. Ministry of Environment Land and Parks (no longer in existence)

MSRM	B.C. Ministry of Sustainable Resource Management
MTTC	Musgamagw Tsawataineuk Tribal Council
MWLAP	B.C. Ministry of Water Land and Air Protection
NAAHP	National Aquatic Animal Health Program
NASCO	North Atlantic Salmon Conservation Organization
NASFI	North Atlantic Salmon Farming Industry
NMFS	National Marine Fisheries Service (U.S.)
NOAA	National Oceanic and Atmospheric Administration (U.S.)
NWPA	Navigable Waters Protection Act (federal)
OCAD	Office of the Commissioner for Aquaculture Development (federal)
OIE	Office International des Epizooties (World Animal Health Organization)
OSA	Office of Sustainable Aquaculture (federal)
PBS	Pacific Biological Station
PFRCC	Pacific Fisheries Resource Conservation Council
PSARC	Pacific Scientific Advice Review Committee
SAR	Salmon Aquaculture Review
SARA	Species at Risk Act (proposed, federal)
SFU	Simon Fraser University
UBC	University of British Columbia

COMPARISON OF PFRCC REPORT ON AQUACULTURE (2003) TO SALMON AQUACULTURE REVIEW (1997)

	Assessment of Environmental Risks				
Topic	**SAR,1997**	**PFRCC, 2002**	**Analysis**	**Work to-date**	**Upcoming work**
FISH HEALTH *sea lice*	The increased number of susceptible hosts found in the farm environment may cause increased numbers of lice in the area immediately around infested farms. Sea lice researchers have not yet been able to determine a spread of sea lice from farmed fish to wild fish; available evidence indicates that the original source of lice is wild fish.	No direct evidence of increased impacts on wild salmon; however, concerns are mounting as evidence emerges that the presence of farms *may* increase infestation in wild stocks. Farms may act as "disease reservoirs" and increase wild fish exposure to infectious agents. Survival time of lice may also be cause for concern.	Concerns have increased over time as information is presented of a link between fish farms and sea lice infestations in wild salmon More research is needed, particularly in determining "natural" infestation rates in wild stocks not exposed to farms. Farm management can reduce numbers of lice (e.g. during migration events) PFRCC INDICATES INCREASED RISK.	MAFF has introduced improved fish health monitoring, reporting and tracking standards and procedures. An industry-wide fish health database is now in place to assist with monitoring trends Fish Health Management Plans must be prepared and followed by all licensed facilities; farmers must maintain high standards for fish health and husbandry and must follow defined acceptable practices for aquaculture as prescribed in their Management Plans. A workshop involving veterinary experts and industry was conducted in June 2002 to identify risk factors associated with the IHN outbreak and potential management actions. A follow up workshop involving veterinary experts and industry to prioritize research proposals regarding the IHN virus was completed in January 2003.	A workshop is planned for early 2003 to finalize an action plan for monitoring and reporting, management actions and research related to sea lice. Provincial and federal governments, the aquaculture industry and non-governmental organizations will be represented. Ongoing monitoring of emerging information in all areas of fish health will inform future modifications to the provincial approach.
bacteria (e.g. furunculosis, BKD)	Furunculosis has historically been diagnosed in wild and cultured fish; no conclusive evidence that agents have been transmitted from farmed to wild fish in B.C.	Risk exists but is minor; wild salmon are generally well adapted to indigenous bacteria; no direct evidence of transfer from farmed to wild; effective use of antibiotics reduces risk.	Bacterial agents pose a minimal risk to wild stocks. PFRCC INDICATES NO CHANGE FROM SAR		
viruses (e.g. IHN, ISA)	Conclusive evidence was not found that indigenous disease agents have been transmitted from farmed to wild fish. Noted that diseases of farmed salmon in B.C are indigenous to the area.	Pacific salmon have natural resistance to indigenous pathogens; however, migrating salmon could be exposed to higher levels than normal when passing an infected farm; survival time of some viruses is sufficient to pose a significant risk.	Risks to wild salmon of viruses from farms are present but are relatively low. PFRCC INDICATES INCREASED RISK.		
exotic diseases	There is a very low probability that exotic disease will enter the province and cause measurable negative effects to indigenous fish populations; however, if it occurred, serious adverse effects.	Unlikely that exotic diseases would be introduced via farm fish due to effective disinfection measures; serious consequences if exotic diseases are introduced.	Risk is low; however, consequences would be serious if an exotic disease was introduced PFRCC INDICATES NO CHANGE FROM SAR.		
"new" diseases	The greater intensity of observation and sampling on farms means it is more likely that previously unrecognized diseases will be found first in farmed salmon.	The probability of new strains of diseases developing through salmon aquaculture and negatively impacting wild salmon is minor.	Not a serious threat; continued monitoring is required. PFRCC INDICATES NO CHANGE FROM SAR.		
high fish densities on farms	A wild population may be at increased risk of infection from pathogens as salmon farming may increase the exposure opportunities for wild fish to disease causing pathogens.	Conditions of high densities of fish on farms may increase susceptibility of farm fish to disease by increasing stress and will increase the probability of disease transfer among farm fish.	Possible health risks to wild fish associated with high stocking densities on farms; primary risk is to health of farm fish. PFRCC HAS SIMILAR CONCLUSIONS TO SAR		

COMPARISON OF PFRCC REPORT ON AQUACULTURE (2003) TO SALMON AQUACULTURE REVIEW (1997)

ESCAPES *survival & spawning*	Extensive recoveries of Atlantic salmon have been reported; No spawning of escaped Atlantic salmon has been documented in B.C. or Washington streams.	Farm fish adapt poorly to survival in the wild; small numbers have successfully spawned; over a greater period of time, spawning may meet with greater success. Recommends continued monitoring.	Atlantic salmon can survive in the wild and some have spawned, but no evidence to date of large-scale spawning success. PFRCC INDICATES NO EVIDENCE OF SERIOUS RISKS	New escape prevention standards were introduced in the provincial Aquaculture Regulation in April 2002. Farmers must exercise increased caution when conducting high-risk activities such as changing nets and transferring live fish. Escape numbers have declined and are in 2002 were among the lowest on record. Government has committed to a zero escape objective.	The province will continue to support monitoring efforts through programs such as Atlantic Salmon Watch. Ongoing monitoring of emerging information in all areas of fish escapes and farmed fish-wild fish interactions will inform future modifications to the provincial approach.
colonization	Reproductive colonization of Atlantic salmon in British Columbia is unlikely, but cannot be ruled out with continued escapes from fish farms.	Only small numbers of feral Atlantic juveniles have been found to-date, suggesting a minimal possibility of colonization in the future.	Colonization has not occurred but a slight risk cannot be ruled out. PFRCC INDICATES NO CHANGE FROM SAR.		
genetic risks	Hybridization between Atlantic and Pacific salmon is highly improbable; risk of genetic damage to wild stocks is potentially high if large numbers of Pacific salmon escape and successfully interbreed with wild stocks over a number of years.	Risks of escaped farm salmon inter-breeding with wild salmon (and reducing genetic diversity) are small when considering Atlantic salmon but are significant when considering Pacific salmon.	Genetic risks when farming Pacific species are the more serious potential consequence of escapes. Risks are much lower with Atlantic species. PFRCC INDICATES NO CHANGE FROM SAR.		
ecologicall habitat risks	At current levels of escapes, the inter- and intraspecific competition between farm and wild stocks (for food/habitat) is not considered to be a threat to wild populations.	Atlantic and Pacific escapees are both capable of disrupting wild salmon habitat and spawning behaviour and of competing with wild salmon for food and space.	Although habitat disruption by escapees is possible, the small numbers found in BC rivers to date is insufficient to warrant serious risk. PFRCC INDICATES NO EVIDENCE OF SERIOUS RISKS.		
OCEAN EFFECTS *seabed impacts of farm wastes*	Effects will vary depending on specific conditions at the site. Benthos would recover within 6-12 months for most sites. Review was unable to properly assess risks in absence of substantive data.	Effects of farm waste on some sea life are possible, but no evidence of direct impacts of wastes on wild salmon; indirect impacts are possible if changes occur lower in the food chain.	New modeling and waste monitoring data have shown the ocean bottom may be affected by farms, but that this effect is reversed when sites stop production or enter a fallowing period. PFRCC INDICATES NO EVIDENCE OF LONG-TERM EFFECTS	New regulations governing farm-generated wastes were introduced in Sept '02. If presence of specified indicator chemicals exceeds a defined level, farms will be required to alter production, operation or management practices.	The new regulation will be reviewed within three to five years to evaluate its effectiveness and consider if amendments are required.
bloodwater & mort disposal	Fish offal and blood water are only associated with processing in British Columbia, an industry that operates under guidelines for waste disposal and handling.	Wild salmon could be negatively impacted if disposal of diseased morts or bloodwater coincides with migration past the site. Otherwise it is unlikely that diseases would be transmitted to wild fish from infected morts or blood water.	Morts and bloodwater must be disposed of in accordance with provincial and federal legislation. Risks are minimal if proper procedures are followed. PFRCC INDICATES NO EVIDENCE OF SERIOUS RISKS	Under new waste regulations, farmers must prepare a best management practices plan which lays our each farm's mort disposal procedures. Mort disposal must comply with the new regulations and the *Waste Management Act*.	BC Aquaculture R&D Committee is preparing to issue funding for research into the management of bloodwater.
cumulative impacts	C.I. should be a factor in the selection of suitable farm sites. Recommends further studies of the cumulative effects of farm wastes and farm concentration.	Impacts from non-salmon farming activities, coupled with growth of fish farming, may have detrimental effects on wild fish. Insufficiently studied.	Cumulative impacts of salmon farming (combined with other activities) deserves consideration. RISKS IN THIS AREA ARE RELATIVELY UNKNOWN AND UNSTUDIED.	Farms are now sited in accordance with several resource buffers. The Aquaculture Opportunities Study has identified areas that are more (and less) suitable for aquaculture.	DFO has committed to studying cumulative effects as part of a review under the Canadian Environmental Assessment Act. A predictive model to assess potential cumulative effects is nearing completion.